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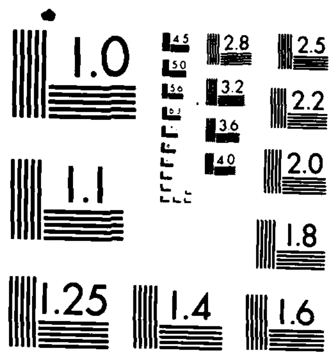

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MEASURING PRODUCTIVITY OF DEPOT-LEVEL AIRCRAFT MAINTENANCE IN THE AIR FORCE LOGISTICS COMMAND

THESIS

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MEASURING PRODUCTIVITY OF DEPOT-LEVEL AIRCRAFT MAINTENANCE IN THE AIR FORCE LOGISTICS COMMAND

THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Systems Management

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Preface

Air Force Logistics Command measures the productivity of its Air Logistics Centers based on Output Per Paid Manday. Output Per Paid Manday measures how many hours out of an eight hour day the worker actually spends performing his/her duties or producing output. Output Per Paid Manday is explained further in Chapter I.

Air Force Logistics Command is interested in alternative methods of measuring productivity. Specifically, the Command prefers a method which uses multiple inputs to arrive at a productivity measure. This thesis uses Data Envelopment Analysis to measure productivity and applies data gathered from the Aircraft Division at the San Antonio Air Logistics Center, San Antonio, Texas.

Throughout the course of my work many people assisted and advised me and I recognize those who were especially helpful. Major William Bowlin, my thesis advisor, guided me through this task and sparked my interest in this research. I am grateful to the persons I worked with at the Aircraft Division who shared their expertise, experience, and time with me which amounted to a crash course on how the Aircraft Division operates. I thank Lieutenant Colonel Ted Novak who accepted to be my thesis reader eventhough he would be assuming new duties as a Defense Contract Administration

Service (DCAS) Commander before I finished. I also thank Mrs. Barbara Pruett of AFLC who suggested I use AFLC as a source for data. Finally, I am very grateful to my wife, Doreen, for her typing support, constant encouragement, and patience during this long task.

Ralph W. Lowry, III

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Abstract

This investigation measures the productivity (efficiency) of the San Antonio Air Logistics Center, Aircraft Division between October 1983 to May 1985. This study consisted of developing a multiple input, multiple output Data Envelopment Analysis (DEA) model and a multiple input single output regression model to measure productive efficiency. The data base consisted of time series data drawing only from the Aircraft Division.

A three input, three output DEA model was developed to analyze 20 months of data. The data was further grouped into quarters to offset the fluctuations inherent in monthly data. The inputs for the DEA model are direct labor actual hours, total material dollars, and overtime hours. The outputs are aircraft delivered on-time, total aircraft produced, and the number of deficiencies found during quality audit inspections.

The regression analysis studied the same inputs but used only total aircraft produced as the dependent variable. The interpretations from the regression analysis are limited because the observations are time series and few in number.

The results of the DEA models showed the Aircraft Division to be 100 percent relative efficient during four of the 20 months studied as well as five out of the seven quarters. Extensive interpretations of the DEA results was restricted due to having data for only 20 months.

The regression analysis only showed that perhaps total labor hours (direct labor hours + overtime hours) could be a predictor of total aircraft produced. No regression model for measuring productivity could be developed from the data due to the limited availability of data.

MEASURING PRODUCTIVITY OF DEPOT-LEVEL AIRCRAFT MAINTENANCE IN THE AIR FORCE LOGISTICS COMMAND

I. Introduction

General Issue

In recognition of limited resources such as labor and materials, the Department of Defense published Department of Defense Directive (DODD) 5010.31, 27 April 1979, and directed that its component organization managers achieve the maximum output with the allocated resources. This initiative is referred to as the DOD Productivity Program, and the objective of the DOD Productivity Program is to increase productivity DOD wide (15:1).

Even beyond DODD 5010.31, Air Force Logistics Command (AFLC) has economic based reasons to be concerned with productivity. Productivity is important to AFLC because the Air Force Air Logistics Centers (ALCs) are competitive organizations. The ALCs do not perform a unique task. Private corporations such as Boeing Aerospace, McDonnell Douglas, Lockheed, and many others are in the business of overhauling and maintaining aircraft. The ALC customers, Strategic Air Command (SAC), Military Airlift Command (MAC), and the Tactical Air Command (TAC) search for the company or

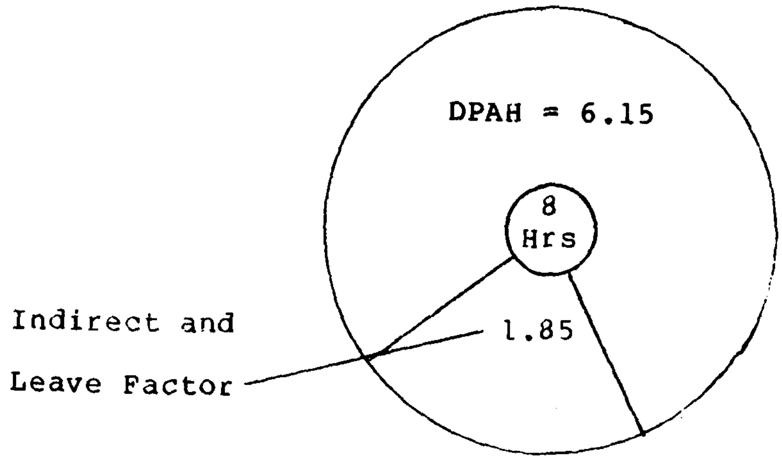
USAF ALC that can service aircraft at the lowest cost. Therefore, due to the competitive nature of the depot level aircraft maintenance business, the Air Force's Air Logistics Centers keep a close eye on productivity so they can provide the best service at the lowest cost.

Background

Currently, AFLC monitors a productivity measure called Output Per Paid Manday (OPMD). "OPMD is that portion of every paid 8-hour day for which direct labor must be produced in the form of production count in duty codes 11 and 12" (33:1). (Duty code 11 refers to direct labor applied to aircraft maintained at the depot and duty code 12 refers to direct labor applied to aircraft maintained at a temporary duty [TDY] location.) Basically, this is a ratio of hours of output per day of work. The output in this measure includes the direct hours a laborer spends working on an aircraft. Output does not include the indirect labor, overhead, or leave (sick and annual). OPMD measures that portion of an eight hour day spent producing a revenue-earning product (the aircraft) (18:3). For example, first realize that not all of the Aircraft Division employees turn wrenches on the aircraft. Individuals who work on the staff or perform administrative tasks are considered overhead.

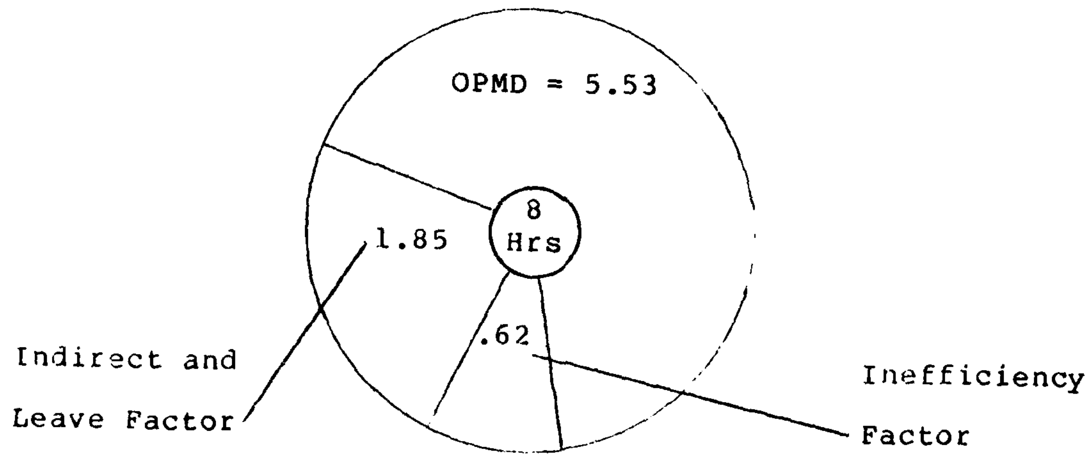
Yet, the cost of their labor is included in the cost of maintaining an aircraft. OPMD only measures the work actually done to the aircraft. Figure 1 helps explain the OPMD calculation. First an indirect factor and a leave factor must be calculated. The indirect factor shows the relationship between indirect labor hours used and the actual direct labor hours used in the production of aircraft (18:4). Similarly, the leave factor shows the relationship between the leave used and the actual direct labor hours used in producing a revenue earning product. The indirect and leave factors are then applied to the eight hour day to determine the direct product actual hours (DPAH). DPAHs are the hours available to be applied by direct labor to accomplish a workload (18:19c). Referring to the top circle in Figure 1, 6.15 hours are applied by direct labor to accomplish the workload while 1.85 hours of an eight hour day are applied to indirect labor and to persons on leave.

The next step is to determine the direct labor efficiency (the bottom circle in Figure 1). This efficiency factor is a ratio of direct product earned hours (DPEH) to direct product actual hours (DPAH). The DPEH are the labor hours earned based on pre-established standard times for accomplishing a job. Essentially, the efficiency factor is a ratio of standard hours to actual hours. This factor (90% in the example) is applied to the DPAH (6.15) to arrive at the OPMD (5.53).



$$\frac{8 \text{ hrs}}{\text{ILF } (1.3)} = 6.15 \text{ DPAH} \qquad (1)$$

$$8 \text{ hrs} - \text{DPAH } (6.15) = \text{ILF } (1.85) \qquad (2)$$



$$\text{DPAH } (6.15) \times \text{Efficiency } (.90) = \text{OPMD } (5.53) \qquad (3)$$

$$8 \text{ hrs} - [\text{OPMD } (5.53) + \text{ILF } (1.85)] = \text{Inefficiency } (.10)$$
$$= .62 \text{ hrs} \qquad (4)$$

Figure 1. Output Per Paid Manday (OPMD) Example

Air Logistics Centers report their measurement of OPMD to HQ AFLC. Air Force Logistics Command uses the OPMD data to assess the productivity of the ALCs, and subsequently, issue to each ALC productivity thresholds for a future period. Typically, AFLC establishes an OPMD measure as a goal for each ALC to achieve.

While focusing on OPMD as the primary measurement of productivity, AFLC implemented an effort aimed at finding other viable measures of productivity. One such effort was directed to finding a method for measuring the productivity of its depot-level maintenance operations. Thereupon, Major Robert F. Horace and Captain Richard E. Hitt, Jr., in an Air Force Institute of Technology thesis, conducted a feasibility study of measuring technical productivity of depot-level maintenance using the Data Envelopment Analysis (DEA) and Constrained Facet Analysis (CFA) models (20). Horace and Hitt conclude that DEA and CFA measure productivity in a way that managers understand and find acceptable for use in decision making.

Their study, however, contains some limitations. First, Hitt and Horace investigated only one shop at only one Air Logistics Center (ALC). Their work would have been more complete had they included similar shops at other ALCs. A second limitation is the output they used from each shop. Hitt and Horace used data from a hydraulic shop that repairs aircraft parts. The researchers could not use the number of

parts repaired as an output but had to manipulate the output by multiplying it by direct labor hours. Thus the output used in the analysis had both input (direct labor hours) and output (number of items repaired) attributes. A pure measure of output should not be the product of an equation where an input is one of the factors. This distorts what the output actually measures.

Statement of the Problem

In a 11 December 1984 letter to the U.S. Air Force Assistant Vice Chief of Staff, Mr. L. K. Mosemann II, Deputy Assistant Secretary of Defense for Logistics and Communications, acknowledged the need for a better technique for measuring depot maintenance productivity.

> I agree with the AFLC belief that productivity measurement trends, based on labor input (output/employee year), are misleading and that productivity trends, based on multifactor input, are a better management tool (29).

This thesis pursues the evaluation of productivity measurement in AFLC. In order for AFLC to decide which productivity measure based on multifactor input is the better management tool, two events must occur: 1) productivity must be measured using a multifactor technique and 2) AFLC management must then assess the value of the productivity measure as a management tool.

Mrs. Barbara Pruett, AFLC/MAJE, identified the aircraft maintenance activity at the Air Force Air Logistics Center in San Antonio, Texas, as a candidate for testing and evaluating a multifactor technique for measuring productivity (31).

The Hitt and Horace research also evaluated a multifactor technique for measuring productivity. However, this thesis differs from their work in two ways. First, they studied one shop with the Sacramento Air Logistics Center, the Pneudralic Motor and Miscellaneous Units Resource Control Center. This thesis, on the other hand, measures productive efficiency of the San Antonio ALC aircraft maintenance activity as a whole. The shop Hitt and Horace used provides support for the primary aircraft maintenance function of the depot. Here, the author measures the efficiency with which the entire depot aircraft maintenance activity employs its resources to accomplish its overall objectives. A second difference between the Hitt and Horace work and this study is the measurement models used. Hitt and Horace used both Data Envelopment Analysis (DEA) and Constrained Facet Analysis (CFA). This work uses DEA and regression models.

In addition to these variations from the Hitt and Horace study, this thesis also expands upon what Mr. Mosemann refers to as multifactor input measurement. The DEA model is capable of measuring productivity in an environment of multiple outputs and multiple inputs.

Research Objectives

1. Define criteria for selecting input and output measures for the Data Envelopment Analysis (DEA) model.

2. Based on these criteria, what inputs and outputs can be used in the model to measure productivity of the San Antonio ALC Aircraft Division?

3. Develop a DEA model for measuring productive efficiency of the Aircraft Division at the San Antonio Air Logistics Center.

4. Develop a regression model for measuring productive efficiency of the Aircraft Division at the San Antonio ALC.

5. Demonstrate the validity of the DEA and regression models as a measures of productive efficiency.

6. What is Air Force Logistics Command management's perception of DEA or regression analysis as a technique for measuring productivity?

Scope

This research applies specifically to the aircraft maintenance function at the San Antonio Air Logistics Center. This study develops a Data Envelopment Analysis

model and adheres to this model's assumptions and limitations that are outlined in the methodology chapter of this thesis. The measurements of efficiency derived in this thesis are developed from and limited to the inputs and outputs defined in the DEA and regression models. Input and output measures constructed in this thesis should not be used to measure productivity in other depot-level maintenance functions without validation of their suitability.

Furthermore, the research covers the time period from October 1983 to May 1985 for the Aircraft Division. The limitations that go along with using such a short time frame are discussed in the results and analysis chapter.

Summary

This chapter has set the groundwork for the remaining pages. The next chapter contains a literature review on productivity. It includes definitions of terms, a United States industrial or commercial viewpoint of productivity, a Department of Defense perspective of productivity, and discussion of various methods used to measure productivity. Chapter III, the methodology chapter, has three sections. The first section defines the criteria for selecting input and output variables then describes the operations and

objectives at the San Antonio ALC. Section two discusses the input and output variables that were considered and selected for this study. The third section describes the DEA and regression models including a comparison and contrast of the two techniques. Chapter IV, Results and Analysis, contains four sections. The first section discusses the data base, followed by the results and analysis of the models' findings. Lastly, the validation of the two models is presented. Chapter V addresses the conclusions of the research and offers recommendations for further study.

II. Literature Review

Overview

This chapter contains a review of literature dealing with productivity in general and, more specifically, productivity measurement. The first section of this chapter defines some of the terms used throughout this thesis. The second section presents a United States industrial or commercial perspective of productivity. The third section explains a Department of Defense perspective of productivity. The fourth section of this chapter discusses different methods used to measure productivity.

Definitions

Productivity: A measurement of the relationship between outputs (the amounts of goods and services produced) and inputs (the quantities of labor, capital, and material resources used to produce the outputs) (30:9).

Efficiency: Comparison of current performance against either a pre-established standard of actual performance or a prior period (16:10). Efficiency is also defined as the ratio of output to input (14:191). A productive operation

is said to be more technically efficient if the same number of outputs is produced using fewer inputs or if more output is produced using the same number of inputs. If the comparison is with respect to a comparison set of other producers, the resulting ratio is said to be a measure of relative (technical) efficiency.

Effectiveness: Comparison of current performance against pre-established mission objectives (goals) (16:10).

Outputs: The goods and services produced for use outside of the organization, which are for delivery to the marketplace or impact on the served sector of the society, geography, or economy, and which are intended to achieve directly the purpose of the organization (26:15).

Inputs: The quantities of labor, capital, and material resources used to produce the outputs (30:9).

United States Industrial Perspective

This section discusses productivity with respect to the United States economy. Two approaches to the U.S. perspective of productivity are used in this section. The first approach addresses reasons why people are concerned about productivity in the United States. The second looks at various causes of changes in productivity.

Why the Concern Over Productivity. One aspect that has contributed to the United States' outstanding economy is consistent productivity growth. Most members of the nation, in one way or another, have benefited from productivity growth through a higher standard of living. Similarly, as the rate of productivity growth declines, which had been the case from the middle 1960s to the end of the 1970s, all members of the nation feel the negative effects of the decline. Recognizing the critical nature of achieving and increasing productivity growth rate in the United States, in 1983 the Committee for Economic Development (CED) published a report which discusses the relationship between productivity growth and the United States economy. This CED report pinpoints the concern over productivity growth in the U.S. economy.

> A key message of this report is that unless the United States is able to achieve and maintain a productivity-growth rate comparable to the rates of other industrial nations, U.S. firms--in almost all sectors of the economy--will find it increasingly difficult to compete in world markets. This will mean the loss of market share for some companies and industries, and loss of jobs for American workers. In addition, if productivity is not substantially improved over the long term, this nation faces the very real prospects of reduced standards of living for all its citizens and of a threatened national security (30:ix).

Another concern over productivity surfaces when comparing the U.S. productivity-growth rate to the rates of other countries such as Japan, West Germany, France, and Italy. The concern here is not only must the U.S. attain an increasing productivity-growth rate but that rate must be

higher than the rates of these other countries so the U.S. can maintain its competitive economic advantage. The Committee for Economic Development emphasizes this concern:

> If the U.S. growth rate continues to lag substantially behind that of other industrialized countries, and if such differences continue for a protracted period, our relative standard of living must decline (30:8).

But the effects of a lagging U.S. productivity-growth rate are not simply a thing of the future. These effects exist right now in our economy. The CED report identifies some examples of markets where many Americans may be familiar with productivity gains of foreign makers.

> In the 1960s and 1970s, a number of American industries found it difficult to retain their shares of foreign markets. Moreover, they witnessed the successful invasion of U.S. markets by foreign products. Imports of automobiles, television sets, radio equipment, and cameras are only some of the most obvious examples (30:27).

Causes of Changing Productivity. Having reviewed some of the concerns arising from a diminishing productivity-growth rate, we now look at reasons why productivity growth fluctuates in the U.S. Some authors, after breaking down the causes of productivity changes into components or factors, try to quantify the impact each factor has on the overall productivity growth of the United States. This section, however, will not address the quantitative impact each cause of productivity change has on overall productivity but rather highlight only the causes of productivity growth (decline) found in the literature.

Kendrick and Grossman (21:15-19) identify quality of labor and changing basic values as two causes of productivity change which relate directly to the labor force. Changing basic values among individuals has had a subtle effect on the productivity of the American workforce. According to Kendrick and Grossman,

> The relevant values, or attitudes, are those relating to the desire for material advancement, the willingness to work hard and to save and invest for the future, the willingness to assume responsibilities and risks, to innovate, and to adapt to change. Some observers claim that the work ethic and the drive for higher real incomes have weakened in the United States during the past decade (21:16).

Kendrick and Grossman go on to admit that this conjecture would be difficult to prove. Easily proven, on the other hand, are the changes in the labor force that Kendrick and Grossman attribute to quality of labor. Three variables affect the quality of labor. First, the education level of the worker affects his/her productivity. As the worker receives more education the worker's productivity increases. A second factor is health and vitality. With a healthier and vital labor pool, labor's productivity is said to increase. The third factor is the age and sex composition among laborers. As a worker ages, matures, and gathers experience his/her productivity improves. Similarly, when the number of women in the labor pool significantly increased, their productivity as a whole increased as more women became experienced, proficient workers.

In addition to Kendrick and Grossman's causes for changes in productivity attributable to the labor component, the Committee for Economic Development (CED) suggests three other factors affecting productivity (30). The first factor, research and development (R&D), is the task of discovering new, more efficient work methods and designs to be applied to the individual workers or manufacturing operations. Some authors use the terms technological innovation (19:136) or productive knowledge (21:16) with the same meaning as research and development. The CED uncovered facts about R&D in its report.

> One recent study reports that private industry in the United States employed 5 percent fewer scientists and engineers in 1975 than in 1970. Also, the share of U.S. patents granted to foreign investors rose from 20 percent in 1966 to 38 percent in 1978, indicating that other industrial nations are now increasing their output of successful R&D (30:35).

Although the Committee found these facts "startling," in their opinion research and development has little relationship with productivity growth.

Government regulation, the second factor according to the CED, perhaps has the most significant impact on productivity growth. Most authors acknowledge government regulation as having a detrimental effect on productivity. According to the CED, government regulations inhibit productivity growth "by reducing the speed and effectiveness with which business decision makers can respond to changing market conditions, by reallocating resources toward less

productive activities; and by increasing the uncertainty of business about future regulation" (30:38). Regulations, however, are not all bad. A trade-off exists where, eventhough the government imposes rules that lower efficiency, these rules and regulations protect the environment and improve the safety of working conditions which enhance productivity in less obvious ways.

The third factor contributing to productivity change is the quality of output. In the recent past, product quality has become equally important as price among manufacturers and consumers when deciding what to produce and what to purchase. Furthermore, consistency must go hand in hand with quality in the manufacturing process.

> Because rejection rates are a significant element of quality in the production process, quality is quite literally an important component of productivity. All other things being equal, the lower a firm's rejection rate, the less its inputs are wasted, and hence the greater its productivity (30:43).

Japan and its success in automobile manufacturing provides relevant evidence of the positive results gained from improving product quality.

This section has covered five causes of productivity change. There exists, however, other causes found in literature but they will not be presented here in detail. Some of these additional factors affecting productivity include capital formation, composition of output, availability and cost of natural resources, quality of land, and the business cycle.

Literature indicates no single dominant factor can explain productivity variations. Instead, the literature findings lend credence to the view that all these factors interact to influence productivity in the United States.

Department of Defense Perspective

The Department of Defense (DOD) perspective of productivity parallels that of industry in the U.S. in that both desire productivity growth. Both perspectives hold as a desirable objective more efficient use of resources and more output from those resources (everything else being equal). Both perspectives differ, however, in the way each measures the progress toward this objective.

> There are no independent measures of [the value of] final output for government (except for government enterprises whose output is sold) or for nonprofit institutions (32:23).

Where the government has no "independent measure" of value for its output, the industrial sector of the United States measures the value of its product using profit. The absence of the profit measure in the Department of Defense is the underlying difference between the industrial and DOD perspectives of productivity. The second part of this section discusses other differences between the DOD (as a nonprofit organization) and a profit oriented organization. The first part reviews some of the concerns the DOD has about productivity in its own organization.

DOD Productivity Concerns. Three literature sources express concerns the Department of Defense holds regarding productivity improvement. From a cost point of view, DOD Instruction 5010.34 highlights the need to minimize costs so that priority objectives can be accomplished.

> Productivity increases are vitally needed to help offset increased personnel costs, free funds for priority requirements, and reduce the unit cost of necessary goods and services (16:1).

This statement indicates a general need for improved productivity through the reduction of costs. A second expression of DOD concern over productivity found in DOD Directive 5010.31 makes a more specific statement. This directive establishes the DOD Productivity Program and tells managers where to focus their concerns in light of the DOD mission.

> The DOD Productivity Program will focus management attention on achieving maximum Defense outputs within available resource levels by systematically seeking out and exploiting opportunities for improved method of operation, in consonance with the Defense Preparedness mission (15:1).

This statement expresses the importance of productivity improvement, however, preparedness remains the primary objective of the DOD.

The third example of the DOD perspective of productivity comes from the Office of Management and Budget (OMB) (28). The OMB stresses competition throughout all sectors of Government. The implication for the DOD is to

either operate more efficiently or lose some operations to private enterprise.

> Competition enhances quality, economy, and productivity. Whenever commercial sector performance of a Government operated commercial activity is permissible, in accordance with this circular and its Supplement, comparison of the cost of contracting and the cost of in-house performance shall be performed to determine who will do the work (28:1).

Therefore, DOD must not only improve productivity for the cost savings benefits, moreover, the motivation to operate more efficiently comes from the threat of losing some of its customers to commercial businesses.

DOD: The Nonprofit Organization. As mentioned earlier, the Department of Defense lacks the profit measure. Thus, one of its goals is to breakeven or not spend more money than what it budgets. Being in this situation implies consequences that do not exist for the profit oriented entity.

Anthony (1:42-43) discusses five consequences of not having a profit measure in an organization. Three of these consequences help illustrate the problems nonprofit organizations, such as the DOD, confront when trying to measure productivity.

According to Anthony, one consequence resulting from not having a profit measure is an unclear relationship between costs and benefits. The corporation, for example, can view alternative courses of action in terms of the costs

and the estimated benefits (revenues) for each action; then pick the optional alternative. The DOD, on the other hand, can determine the costs of particular action, but since these actions (national defense) generate no revenues, the estimated future benefits are more difficult to measure.

Another consequence Anthony discusses is the difficulty of measuring performance. For instance, assume the DOD wants to measure its efficiency of its entire organization. Its primary goal is to provide a service--national defense. Because the output of this service cannot be quantified (unlike the profit a corporation earns when it provides a service), the efficiency with which DOD meets its national defense goals is difficult to measure.

A third consequence of not having a profit measure, according to Anthony, is the inability to compare performance among units in the organization. In a nonprofit organization, its subunits or departments would have to perform similar functions in order to compare them. Thus, there is no way to compare the DOD with the Department of Agriculture.

Anthony's discussion highlights some of the unique problems nonprofit organizations face. Yet, even without a profit measure, organizations such as DOD employ techniques to measure productivity. Some of these techniques are explained in the next section.

Ways of Measuring Productivity

A review of the literature covering the various methods of measuring productivity reveals no one best technique. According to Dogramaci (19:5), the interpretation of a particular productivity measure depends upon how the measure is calculated. This implies many meanings of productivity may exist. Similarly, the Committee for Economic Development (30:10) reported that there is no correct way to measure productivity and the technique used depends upon how one defines the concept of productivity. This section will not discuss the various definitions of productivity, instead, it explains some of the methods used to measure productivity. Four different ways of measuring productivity presented here are: labor ratios, total factor productivity, productivity audits, and checklist indicators.

Labor Ratios. A labor ratio or labor index compares the amount of labor (based upon hours worked or cost of the labor) to an output produced. For example, the Bureau of Labor Statistics computes indexes of output per manhour in the private sector as a ratio of "Gross Domestic Product originating in the private or individual sectors to the corresponding hours of all persons employed" (19:6). According to Rees, this measure presents a problem, "At present, BLS price indexes account for improvements in

products or services that are associated with higher costs to the producer" (32:24). In other words, this ratio mixes price and technical efficiency so that if a producer pays more for his resources and increases the price of the output as a result of it, then this is interpreted in the index as an improvement in quality or productivity. Another problem with the BLS measure in particular and labor ratios in general is that this approach fails to consider other sources of variation in productivity such as capital investment and improved management techniques.

Total Factor Productivity. According to Mali (25:91), total factor productivity compares output to all of the inputs used to produce the output simultaneously. A mathematical equation best describes this measure:

$$\text{total factor productivity} = \frac{\text{output}}{\text{labor} + \text{capital} + \text{resources} + \text{miscellaneous}} \qquad (5)$$

This technique is thought to move closer to the realities of productivity because all of the input components used to make the output are included in the equation. The difficulty, however, is to accurately identify the inputs used and the proper quantities of inputs used to produce the output. Another problem is that these indexes are difficult to construct so that they identify the different input sources of variation in output. Finally, they are difficult

to construct for the multiple output environment of nonprofit organizations.

Productivity Audits. Productivity audits move away from the objective measures of productivity toward a subjective measure. Mali defines the productivity audit as:

> . . . a process of monitoring and evaluating organizational practices to determine whether functional units, programs, and the organization itself are utilizing their resources effectively and efficiently to accomplish objectives. Where this is not being achieved, productivity auditing recommends necessary action to correct and adjust shortcomings, poor results, and system deficiencies (25:132).

Mali also suggests a model for conducting a productivity audit. This model includes (1) determining the audit's purpose, (2) selecting standards as measurement criteria, (3) compare measures with the standards, (4) correct deficiencies, (5) write a report. Mali implies that developing an audit is subject to a number of constraints such as cost, time, and manpower. In addition, he glosses over the problems of identifying and formulating standards suitable for the productivity audit objectives. These problems make the reliability of the audit questionable.

Checklist Indicators. Mali suggests another subjective method for measuring productivity called checklist indicators.

> Productivity checklist indicators represent judged actions by senior or experienced practitioners that would do the job needed. Checklist indicators may

> represent a consensus of several practitioners on the important steps or items that would solve a problem or lead to the needed level of productivity (25:99).

Once the checklist is developed the evaluator goes to the organization and compares what actually has occurred or currently takes place to the indicators on the list. As the evaluator verifies an indicator on the list, he checks it off. Following the evaluation the evaluator calculates a productivity index comparing the number of indicators checked to the total number of indicators on the checklist. Although an index is calculated, composing the checklist itself invites subjective input from the practitioners who developed the indicators.

Summary

This chapter reviewed literature concerning productivity. The first section defined terms that will be used in this thesis. Then productivity was discussed from the perspective of United States industry. The third section presented a Department of Defense perspective of productivity. Finally, this chapter explained some of the methods used to measure productivity. Neither Data Envelopment Analysis nor regression were included in the final section, instead they will be discussed in detail in the next chapter.

III. Methodology

Overview

This chapter explains the methodology of this research. The following research objectives guide the research approach:

1. Define criteria for selecting input and output measures for the Data Envelopment Analysis (DEA) model. (These same data are used in the regression model.)

2. Based on these criteria, what inputs and outputs can be used in the models to measure efficiency of the San Antonio ALC Aircraft Division?

This chapter is divided into three sections. The first and second sections address research objectives one and two, respectively. The third section reviews literature on DEA and regression through a comparison and contrast of the two techniques.

Defining the Criteria for Selecting Input and Output Measures

Input and output measures used in DEA should match closely with the overall purpose or objectives of the

organization being measured. The organization's objectives provide the criteria upon which input and output selection is based. The author visited the Aircraft Maintenance Division of the San Antonio Air Logistics Center at Kelly Air Force Base, Texas, to get a first hand look at the aircraft depot maintenance operations and meet with key personnel to determine the objectives of the activity. Before discussing the specific purpose of the aircraft depot maintenance activity, it is pertinent to understand basically how the facility operates.

Depot Aircraft Maintenance Operations (23). The Aircraft Division is a competitive organization. In addition to competing with other ALCs for existing and new organic workloads, the Division must compete with private corporations which do similar work, such as Boeing Aerospace or McDonnell Douglas, to acquire new workloads. Consequently, if the Aircraft Division cannot work on an aircraft for a competitive price, they will lose that business to private industry.

The depot performs two major types of work on the aircraft. One type is periodic in nature called Programmed Depot Maintenance (PDM). The other type of work includes new, non-periodic tasks which may be one time jobs or modifications. This is called mod work. Both types of workload are discussed below.

Before the start of each fiscal year, the Aircraft Division negotiates with its customers' System Manager (SM) and the AFLC Maintenance Requirements Review Board (MRRB), for the coming year's workload, work requirements, and hours. The San Antonio depot maintains B-52G, B-52H, C-130, OV-10, and C-5A aircraft. During this negotiation process, the depot and the customer agree to delivery dates of finished aircraft and the negotiated labor hours for the contracted work which are based on standards. Headquarters AFLC issues these standards to the ALCs and they are based on historical data for similar maintenance tasks. The negotiated workload is usually called Programmed Depot Maintenance (PDM). Once the aircraft arrives at the depot for maintenance, the aircraft is inspected. Inspectors may find parts of the aircraft that need repair or maintenance which were not originally included as part of the negotiated work. These unanticipated tasks are called "over & above" work. After approval by the SM Project Administering Officer (PAO), the "over and above" work becomes part of the PDM, the added work is accomplished, and the originally agreed upon hours are changed, if necessary, to include the labor hours spent on the over and above work.

The other major category of work done to the aircraft is called modification or mod work. Mod work can include the overhaul or maintenance of existing aircraft parts or components. It also consists of replacing old components

with new versions of the old components. In a simplified example, a modification may consist of replacing old black boxes with new ones to update the aircraft's avionics.

After the aircraft is made safe--fuel drained, tanks purged, and the aircraft is washed--and the initial aircraft inspection (discussed above) is accomplished, the scheduled work begins. The aircraft is dismantled and certain components are job routed to different shops throughout the depot for either repair or modification. For example, wing flaps may be sent to have new "skin" applied. The repair/modification of the airframe and installation of the repaired and replacement parts and components (the actual reassembly of the aircraft) takes the longest time. After a series of various system operational checks and inspections, the aircraft is given a preflight inspection in preparation for a Functional Check Flight (FCF). After any deficiencies are corrected and the preflight testing is complete, the depot's flight crew performs the FCF. After an acceptable FCF, the aircraft is either picked up by or delivered to the customer.

Depot Aircraft Maintenance Objectives. Having a basic knowledge of the depot aircraft maintenance operations, the author discussed the organization's main objectives with experienced managers in the Aircraft Division (2, 22). These individuals pointed to the aircraft delivery schedule

as the first major objective of the organization. They considered finishing the aircraft by the scheduled delivery date as the most important goal. Delivering early is not perceived as necessarily better than delivering on the scheduled date. On the other hand, one day late is just as bad as one week late. The second objective, and a very important one, is returning a quality aircraft to the customer. Quality means returning an aircraft to the customer that meets work specifications and offers no threat to the safety of the flight crew.

In addition to the major objectives of on time delivery and aircraft quality, Aircraft Division managers highlighted six other important depot aircraft maintenance objectives.

1. Cost effectiveness. This goal can be interpreted in terms of "profit and loss." Each year the depot negotiates its workload with its customers. At that time, the hours required to perform the workload are agreed upon. This goal is to do the negotiated work within the set hours.

2. Facility Utilization. This objective is to use available manpower all of the time and facilities as scheduled. In other words minimize manpower and facility idle time. Facilities include the hanger where the aircraft are dismantled and the paint hanger.

3. Material Usage. This goal is to maximize the efficient use (minimize waste) of non-exchangeable materials such as towels, tape, hardware (nuts and bolts), etc.

4. Safety. This objective refers to safety in the work place and the protection of the ecological environment.

5. Reduction of Overtime. Each year after negotiating the coming year's workload, a particular number of hours are budgeted for overtime. This objective is to minimize the use of overtime in excess of the budgeted overtime.

6. Training. Basically, two categories of training exist: new employee (with previous experience) and apprentice. New employees must be upgraded to the skill level required to do their assigned job. Apprentices begin from knowing nothing about aircraft maintenance to becoming a journeyman. The goal is to have enough skilled workers to do the assigned jobs for each aircraft.

The above eight objectives: schedule, quality, cost effectiveness, facility utilization, material usage, safety, reduction of overtime, and training, form the criteria upon which input and output selection is based. Having established these criteria, this answers the first research objective.

Selecting Input and Output Measures

Using the criteria outlined above, the author, with knowledgeable personnel in the aircraft maintenance organization assisting, selected candidate inputs and

outputs for this analysis. In addition to the criteria developed earlier, four conditions helped guide the data selection (3:29-30).

1. The inputs and outputs should be inclusive of all aircraft depot maintenance activities. The measures should "fully and properly" represent the maintenance activity.

2. The inputs and outputs should be related such that an increase (decrease) in an input can be expected to cause an increase (decrease) in an output.

3. Inputs and outputs should exist in positive amounts.

4. The data should be documented (written down) so that it cannot be manipulated so as to influence the results of this analysis.

Outputs Considered and Selected. The following outputs were investigated as possible output measures.

1. Schedule. This measure represents the number of aircraft delivered to the customer on-time. Early deliveries are the same as on-time deliveries.

2. Quality. The quality assurance personnel of the Aircraft Division perform a Ready-For-Delivery (RFD) quality audit of each aircraft before its functional check flight. The quality audit results in either a satisfactory or unsatisfactory rating for the aircraft. The aircraft's rating depends upon the number of critical, major, and minor

findings on the aircraft. The total number of findings (critical + major + minor) is considered a surrogate for the quality of work performed to each aircraft. Since a lower number of findings is more desireable then a higher number and DEA assumes increases in output in response to increases in input, the reciprocal of the total findings is used in the DEA model.

3. Total Aircraft Produced. Aircraft production includes the total number of aircraft the Division maintains and/or modifies during a given time period whether or not the aircraft were completed on-time.

4. Number of Reworks. A rework (or a "re-repair") occurs when a quality audit finds a deficiency in a completed job (aircraft). The deficiency must then be corrected resulting in a rework.

5. "Profit - Loss." This output measures the amount by which planned (negotiated) revenue exceeded (fell short of) total cost of completed work. This can be put in the form of an equation: planned revenue - total cost = profit (loss). Revenue in this case means payment the depot receives from its customers for the negotiated workload.

Out of the five candidate outputs, the first two, schedule and quality, were initially selected for this analysis. Then, as discussed in the next chapter, analysis of the DEA results led to including the third output, total number of aircraft produced. Output four, number of

reworks, was not selected because this measure also represented quality of aircraft maintenance work and, in the opinion of expert personnel, the quality audit rating is a better measure of quality. The "profit - loss" output was also not selected because it does not indicate a true profit or loss posture. The depot's revenue is based on standard costs applied to a negotiated workload. Therefore, the "profit or loss" generated after a completed job indicates how well the standard rates reflect the actual cost of doing the job.

Inputs Considered and Selected. After reviewing the possible output measures, the following input candidate were investigated.

1. Labor hours available. This input represents the number of actual direct labor hours available to work on an aircraft and its parts.

2. Material Usage. This input measures the total cost of materials used. Direct materials refer to material used specifically for an aircraft. For example, sheet metal for a fuselage. Indirect material includes material used to support the aircraft maintenance or overhead material. Indirect material costs do not apply to any one particular aircraft.

3. Overtime. This output is the number of hours of overtime worked in excess of overtime hours budgeted. This

measures how much of the work is able to be accomplished within the planned time.

4. Facility's Age. The age of the facilities at the depot, as an input, represents the degree of building modernization. The relationship here is that facility age reflects a building's layout/design, complexity, and aircraft accessibility. Older buildings would tend to have a more complex design thus inhibit their efficient use with modern aircraft. For example, the paint facility at San Antonio has one door for entry and exit. A newer paint facility may have two doors one for entry and one for exit (like a car wash). This building design would enhance the productivity of the paint facility.

5. Environment Impact. If the depot were ever found to be violating environmental safety standards, operations would stop until the problem was corrected. This input measures the number of environmental safety violations that occur in the aircraft maintenance operation.

6. Tool Searches. The depot issues tools to each individual who requires tools to work on an aircraft. The tool count is controlled and the worker is responsible for tools issued to him. If a tool is missing when the worker returns the tools issued to him, the worker performs a tool search to try to find the lost tool. This input measures the number of tool searches conducted during a given period of time. As tool searches increase, output should decrease.

So the input variable would be the reciprocal of the number of tool searches.

Out of the six candidate inputs the first three, direct labor hours available, material usage, and overtime hours were selected for this analysis. Facility's age was not selected because the assumption that age represents efficient design is not necessarily valid. Although, based on the observations of depot personnel, newer facilities with different designs could influence the productivity of the Aircraft Division. Also, there were no design changes over the period reviewed; therefore, this input would have no impact. Environmental safety was not selected as an input because the depot has an excellent record in this area and has never been shut down because it has endangered the environment. The area surrounding the depot is inspected regularly, however, for possible violations. Finally, tool searches were not selected because they have a minimal impact on direct labor hours diverted from aircraft maintenance work.

In summary, this thesis uses three inputs and three outputs. The inputs are direct labor hours, cost of materials used, and overtime hours. The outputs are the total number of critical, major, and minor findings from the Ready-For-Delivery quality audit inspections and the number of aircraft completed on-time, and the total number of aircraft produced.

Data Envelopment Analysis and Regression

This section contains two parts. The first part describes the Data Envelopment Analysis (DEA) model using a simple example of its application. The second part addresses the third research objective by comparing and contrasting the DEA and regression models as ways of measuring efficiency.

Data Envelopment Analysis. Data Envelopment Analysis (DEA) appeared in the literature in 1978. The developers, Charnes, Cooper, and Rhodes (10) employed DEA to evaluate government supported programs in public schools. Unlike profit oriented organizations, nonprofit entities (like the U.S. Air Force) have no common measure of efficiency of operations. In the absence of a comprehensive measure of efficiency such as profit, DEA provides a method whereby organizations operating for similar purposes and which have decision making authority over the use of their resources can be compared to one another. To make this comparison, DEA uses multiple inputs and multiple outputs from each organization to compute the efficiency of an organization as it relates to others in the comparison set.

In DEA terminology, an organization that has decision making authority over the use of its resources in order to produce output is called a Decision Making Unit (DMU). For example, Charnes and others (8) researched the efficiency of maintenance organizations in the U.S. Air Force. They studied 14 Air Force Wings. Each Wing constituted one DMU. In a similar fashion, one organization can be compared to itself over time. For instance, if an organization has been in operation for ten years, then each year of operation is considered one DMU. The organization can then compare its operating efficiency between different points in time.

A closer look at the decision making unit finds each DMU using a combination of inputs to generate some type of output. DEA requires that DMUs be similar in nature so that each DMU uses similar input to generate similar output. This important aspect supports the "relativity" of the efficiency measurement that DEA calculates. One hundred percent efficiency for DEA does not mean a particular DMU is 100 percent efficient compared to a previously known parameter. Rather, the DEA efficiency measure is a relative measure.

> One hundred percent relative efficiency is attained by any DMU only when comparisons with other relevant DMUs do not provide evidence of inefficiency in the use of any input or output (9:18).

One hundred percent efficiency is achieved by any DMU when either of two conditions exist. Under one condition, a DMU is 100 percent efficient when it cannot increase its output

without either using more inputs or generating fewer of its other outputs. A second condition for 100 percent efficiency is when a DMU cannot use less input without either producing fewer outputs or using more of another input (9:17). An example of DEA may clarify these concepts.

The following example illustrates the results of a DEA analysis (Figure 2). This simple example assumes five DMUs (A, B, C, D, and E) using a two input, one output case. The X - axis represents the quantity of input 1 consumed and the Y - axis represents the quantity of input 2 consumed. The solid line connecting points A, B, and C represents a section of the unit isoquant for one unit of a single output. The X and Y coordinates of points A, B, C, D, and E represent observed inputs used to produce the one unit of output by each of the DMUs associated with these points.

Under DEA, a DMU, such as point A in Figure 2, is considered efficient since there is no other DMU or convex combination of DMUs which produces the same output with less of at least one input. An efficiency frontier consists of the convex combinations of all such points. Any movement along this frontier requires trade-offs between inputs 1 and 2 in order to stay on the frontier. The DMUs, such as A, B, and C in Figure 2, located on the efficiency frontier are 100 percent efficient relative to the other DMUs in the comparison set.

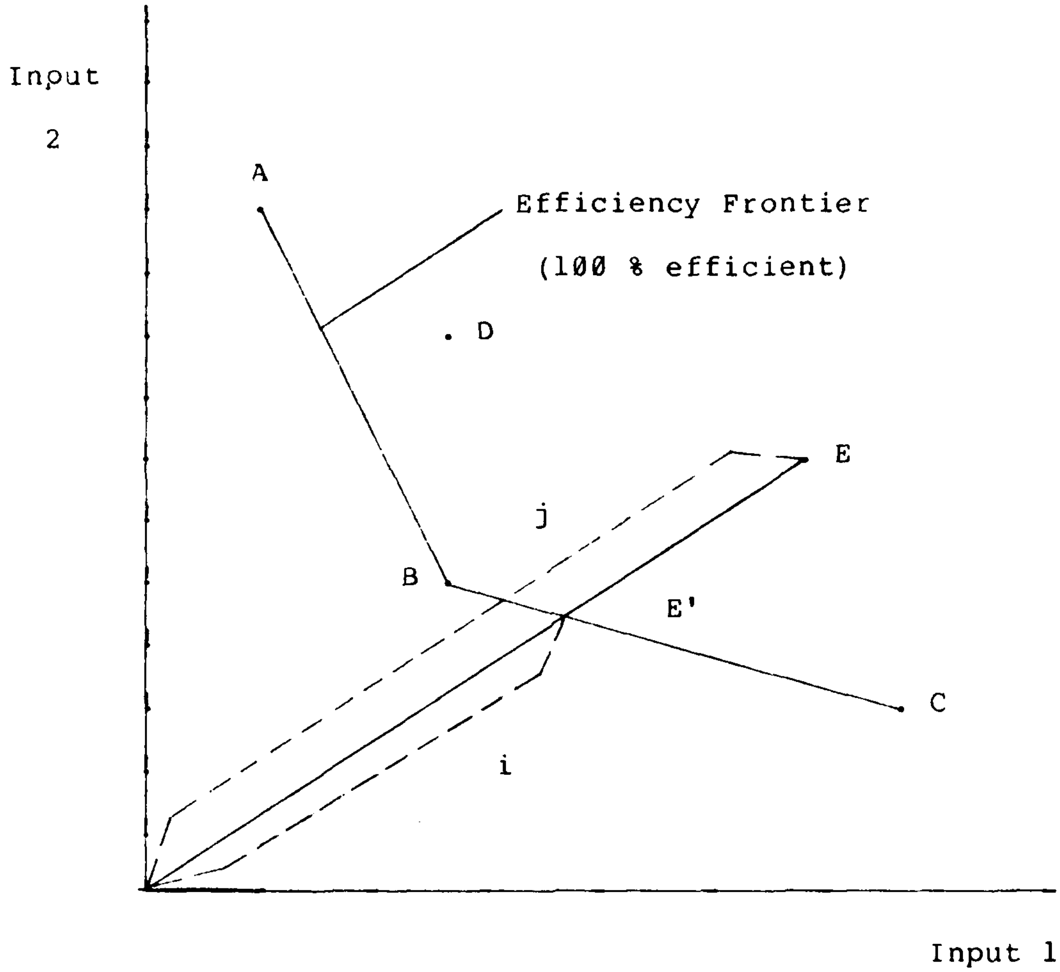


Figure 2. Example of Data Envelopment Analysis

DMUs D and E, however, are not on the efficiency frontier and therefore are less than 100 percent efficient. There are convex combinations of A and B and B and C, respectively, which produced the same output with fewer inputs. The measurement of efficiency for DMUs D and E is computed in relation to the efficiency frontier. The efficiency measure for DMU E is the ratio of two Euclidean distances. The denominator equals the distance from the origin to DMU E (distance j in Figure 2) and the numerator equals the distance from the origin to the efficiency frontier (distance i in Figure 2) where E' is a convex combination of points B and C. One can observe that this ratio equals a percentage greater than 0 but less than 100. The same procedure applies to calculating the efficiency measure of DMU D.

Mathematical DEA Model. The graphical interpretation of DEA just discussed evolves from the mathematical formulation of DEA. Charnes, Cooper, and Rhodes (10) introduced the mathematical formulation of DEA as a ratio of multiple outputs to multiple inputs shown below.

$$\text{Maximize:} \qquad h_0 = \frac{\sum_{r=1}^{s} U_r Y_{r0}}{\sum_{i=1}^{m} V_i X_{i0}} \;. \tag{6}$$

Subject to:

$$1 \geq \frac{\sum_{r=1}^{s} U_r Y_{rj}}{\sum_{i=1}^{m} V_i X_{ij}} \tag{7}$$

$$j = 1, \ldots n$$

$$U_r,\ V_i \geq \epsilon > 0$$

where

h_0 = the efficiency measure for DMU "0" which is the DMU being measured relative to the other DMUs.

X_{i0} = the observed amount of the ith input used by DMU "0" during the observed period.

Y_{i0} = the observed amount of output "r" that DMU "0" produces during the observed period.

X_{ij} = the observed amount of the ith input that DMU "j" produces during the observed period.

Y_{ij} = the observed amount of output "r" that DMU "j" produces during the observed period.

V_i and U_r = values the model determines directly from the data to be used in the function.

ϵ = a small, positive non-Archimedian constant (6:3-4).

Charnes, Cooper, and Rhodes have transformed this fractional programming problem into an equivalent linear programming problem using the theory of linear fractional programming. Charnes and Cooper developed their theory and discuss the mathematical transformation in detail in reference (10). The linear programming equation is presented below.

Minimize: $$h_0 = \theta - \epsilon \left(\sum_{r=1}^{s} S_r^+ + \sum_{i=1}^{m} S_i^- \right) \tag{8}$$

Subject to: $$\sum_{j=1}^{n} Y_{rj} \lambda_j - S_r^+ = Y_{r0} \tag{9}$$

$r = 1, \ldots S;$

$$-\sum_{j=1}^{n} X_{ij} \lambda_j - S_i^- + \theta X_{i0} = 0 \tag{10}$$

$i = 1, \ldots m$

$\lambda_j, S_r^+, S_i^- \geq 0$

θ unrestricted in sign

where

θ = the intensity multiplier of input $Xi0$,

λ = variable determined by the model,

S_r^+ = output slack value for output "r",

S_i^- = input slack value for input "i",

ϵ = a small, positive non-Archimedian constant (6:9-10).

DEA is unlike other more commonly used statistical techniques such as regression. Thus, in addition to the above example of DEA, one can get a better understanding of DEA when it is compared and contrasted to regression.

Regression Analysis. Before regression and DEA are compared and contrasted in the next section, this section discusses the methodology for the regression analysis used in this thesis. Regression analysis allows researchers to observe the effect of one or more independent variables upon a dependent variable. Using the data from the San Antonio ALC, the independent variables for the regression model in this thesis are direct labor hours, material costs, and overtime hours. The initial dependent variable is the number of on-time deliveries. This ouput was selected as the dependent variable over the quality output variable because of Aircraft Division management's primary emphasis on meeting its schedule objective. This was later modified to having total aircraft produced as the dependent variable because on-time deliveries did not capture sufficiently the production of the Division.

Productivity (efficiency) of the Aircraft Division will be measured using a ratio of the actual total number of aircraft produced over the total aircraft production estimated by the regression equation for the given inputs (independent variables).

DEA Versus Regression. Chapter IV analyzes data using both the DEA and regression models. Before we look at that analysis, this section discusses some of the similarities and differences of the two methods.

In comparing DEA and regression we find two similarities. First, both DEA and regression can use multivariate data. Like DEA, regression can look at the relationship between several independent variables and one dependent variable. As an extra feature, however, DEA can analyze the relationship between multiple inputs (independent variables) and multiple outputs (dependent variables). A second similarity is that both methods can be used to estimate or forecast efficient levels of inputs that an organization should use to attain a particular level of output (assuming that level of output in most efficient). However, for regression, this level of output must be predetermined and it is an average level of output. Whereas DEA is an extremal methodology and calculates an optimal level of output for the particular DMU under evaluation. Perhaps this difference can best be illustrated with Figure 3 which depicts a single output/single input case.

Figure 3 shows a hypothetical case where a regression line fitted through the data represents the average output at different levels of input. On the other hand, the DEA

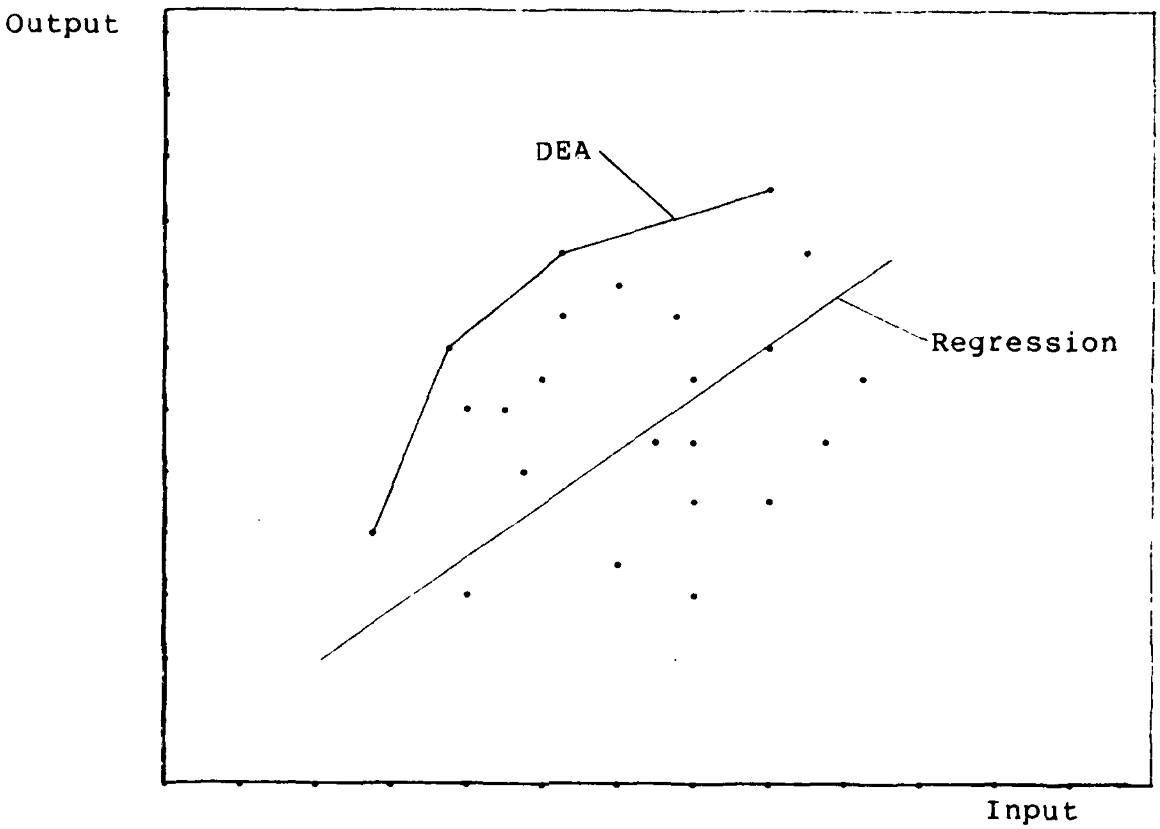


Figure 3. DEA Versus Regression Example
(single output/single input)

efficiency frontier shows the optimal or maximum output which can be produced at different levels of input.

Along similar lines, DEA and regression can be considered alternative approaches for accomplishing the same objective.

> It [DEA] can also be used to obtain estimates of the sources and amounts of inefficiency and in this respect, too, DEA might be regarded as an alternative to uses of regression coefficients which are sometimes used for these purposes (8:2-3).

Although DEA and regression may be considered alternatives, they are not necessarily mutually exclusive techniques. Researchers may use both methods to look at the same data from different perspectives.

> For instance, the usual least squares regression might be used when general characterizations are of interest for purposes of policy analysis and prediction of future behavior of the entire ensemble of observations. DEA might be used when interest centers on individual observations and the institutions (=DMUs) to which they relate (9:3-4).

Furthermore, DEA and regression could be used consecutively "as when DEA is used to adjust or refine the data prior to forming regression estimates" (9:4).

Turning to the contrasting features of DEA and regression, three distinct differences exist. First, DEA does not require a priori specification of functional forms which may or may not be correct as do regression techniques. Second, DEA optimizes on each observation (DMU), whereas regression averages over all observations (8:3). Thus via DEA a manager is able to analyze efficiency variances for his DMU and take the action required to bring inefficient DMUs onto the efficiency frontier. Regression, on the other hand, does not offer such information for the manager to act upon, but simply indicates where an organization should be compared to all observations (5:2). And finally, because regression uses all observations, it includes efficient as well as inefficient observations to arrive at the "best fit" or average. In contrast, DEA differentiates between

efficient and inefficient observations in arriving at its efficiency frontier (5:2).

Complementing the various similarities and differences between DEA and regression, empirical evidence exists which compares analyses using DEA and regression. Bowlin and others (5) studied this subject by applying hypothetical hospital data with known efficiencies and inefficiencies to both DEA and regression. This study showed that "the DEA estimates [of efficient total cost] are almost uniformly better than even the highly creditable regression estimates" (5:32). This thesis also applies data to both regression and DEA. The analysis in chapter four adds to the empirical evidence showing the relationship between DEA and regression.

Summary

Chapter III discussed the methodology used for this thesis. The first two sections answered research objectives one and two.

1. Define criteria for selecting input and output measures for the Data Envelopment Analysis (DEA) and regression models.

2. Based on these criteria, what inputs and outputs can be used in the models to measure efficiency of the San Antonio ALC Aircraft Division?

In addition to answering the research objectives, the third part of Chapter III reviewed the DEA and regression models. The author illustrated DEA using a two input, one output example and explained some of the interpretations of DEA results. Then, DEA and regression were compared and contrasted as methods of measuring productivity.

IV. Results and Data Analysis

Overview

This chapter covers the analyses conducted on the data collected from the San Antonio Air Logistics Center, Aircraft Division and contains two sections. The first section discusses the data collected from the San Antonio ALC, Aircraft Division. The second section presents an analysis of the results of the DEA and regression analysis performed on the data.

Chapter IV addresses research questions three, four, and five.

3. Develop a DEA model for measuring productive efficiency of the San Antonio ALC, Aircraft Division.

4. Develop a regression model for measuring productive efficiency of the Aircraft Division.

5. Demonstrate the validity of the DEA and regression models of measuring productive efficiency.

Data Base

This section describes the sources of the data base for the input and output variables selected in Chapter III.

The input variables are direct labor actual hours, direct labor overtime hours, and total material dollars. The output variables are on-time aircraft deliveries and total number of deficiencies found during Ready-For-Delivery audits, and total aircraft produced.

One very important limiting factor developed during data collection. For some variables data were available for only the past 20 months. The author had hoped to find data reaching back five or six years in order to accomplish an adequate efficiency analysis over time. On the other hand, the data were recorded in monthly increments allowing the author to analyze monthly data and then group the months into quarters creating a second data base and allowing a limited analysis over time. In addition, fluctuations caused by monthly data had to be considered and are addressed later in this chapter as part of the data analysis discussion.

Available data for overtime hours and monthly aircraft deliveries dated back only to October 1983. Eventhough data on other variables reached beyond October 1983, the author studied only the period of time over which complete data was recorded for all the inputs and outputs, October 1983 - May 1985. Appendix A contains the data base.

Inputs. Data for two inputs, material dollars and direct labor hours (direct product actual hours), are

recorded in the GO35A cost report maintained at San Antonio ALC Accounting and Finance. The GO35A reports record material dollars in current dollars. For this analysis, material costs were adjusted to a constant value (October 1983) using monthly producer price indexes in Appendix B (18). The price indexes apply to producers of fixed wing utility aircraft and they provide a general indication of the inflation effect on material costs for aircraft produced at the Aircraft Division. Data for the third input, overtime hours, are maintained by the Financial/ Management Analysis office in the Aircraft Division.

Outputs. The Aircraft Quality Assurance office in the Aircraft Division records deficiencies discovered during Ready-For-Delivery audits. The Material and Product Support office under the Directorate of Maintenance at Headquarters AFLC records data on the second and third outputs, on-time aircraft deliveries and total aircraft produced.

Results and Analysis

Computer Resource. The author used the CDC Cyber 178/845 main frame computer at the Aeronautical Systems Division Computer Center, Wright-Patterson AFB. In order

to perform Data Envelopment Analysis the author used the Multi-Purpose Optimization System (MPOS) software package on the Cyber 178/845 (13). For the regression analysis, the author used the Statistical Package for the Social Sciences (SPSS) software package (27). Appendix C contains samples of the MPOS and SPSS programs used for this analysis.

DEA Results and Analysis. As mentioned earlier in this chapter, the data are monthly observations and come only from the San Antonio ALC. Therefore, one month's data represents a decision making unit (DMU) and hence there are 20 DMUs. Thus DEA measures the relative efficiency of the San Antonio ALC, Aircraft Division over time (20 months).

The first computer run of the DEA model (sample one in Appendix C) used the variables discussed in the previous chapter and yielded the DEA efficiency values (h_0^*) shown in Table I. Note that only two DMUs reached 100 percent relative efficiency. These results indicate that during the 20 month period from October 1983 to May 1985 and based on the selected inputs and outputs only in November 1983 and July 1984 did the Aircraft Division operate at an efficient level relative to the other months. The efficiency rating for the inefficient months indicates the "at best" rating. For example, October 1983 received an efficiency rating of .619. This means that "at best" the

Table I

DEA Efficiency Values (First DEA Model)

Month	DMU	Efficiency
OCT 1983	1	.619
NOV	2	1.000
DEC	3	.905
JAN 1984	4	.741
FEB	5	.646
MAR	6	.685
APR	7	.724
MAY	8	.770
JUN	9	.796
JUL	10	1.000
AUG	11	.856
SEP	12	.688
OCT	13	.413
NOV	14	.833
DEC	15	.494
JAN 1985	16	.899
FEB	17	.405
MAR	18	.581
APR	19	.819
MAY	20	.929

operations during that month were 61.9 percent efficient in comparison to the other months in the data set. Also, it means all inputs could have been reduced by 38.1 percent with the same amount of output being produced. Each inefficient DMU rating can be interpreted in this same fashion.

In addition to the efficiency rating h_0^*, the DEA model also generates input (S_i^-) and output (S_r^+) slack values for the inefficient DMUs. The slack values from the first DEA model are in Appendix D. Input slack represents the amount by which an input can be further reduced beyond the reduction indicated by the h_0^* value and still produce the same level of output. Output slack represents the amount by which output can be further increased even after the indicated input reductions have been made. Input slack values are used to calculate efficient input levels for DMUs later in this chapter.

Further analysis for possible trends in the DEA efficiencies is shown in Figure 4. The graph indicates wide fluctuations in the efficiency values. The author thought the steep fluctuations occurred possibly because the inputs and outputs do not match properly. That is, perhaps the outputs do not fully encompass all of what the inputs produce. DEA output variables should "fully and properly" reflect (or match) what is generated from the consumption of inputs. The question then is what else do

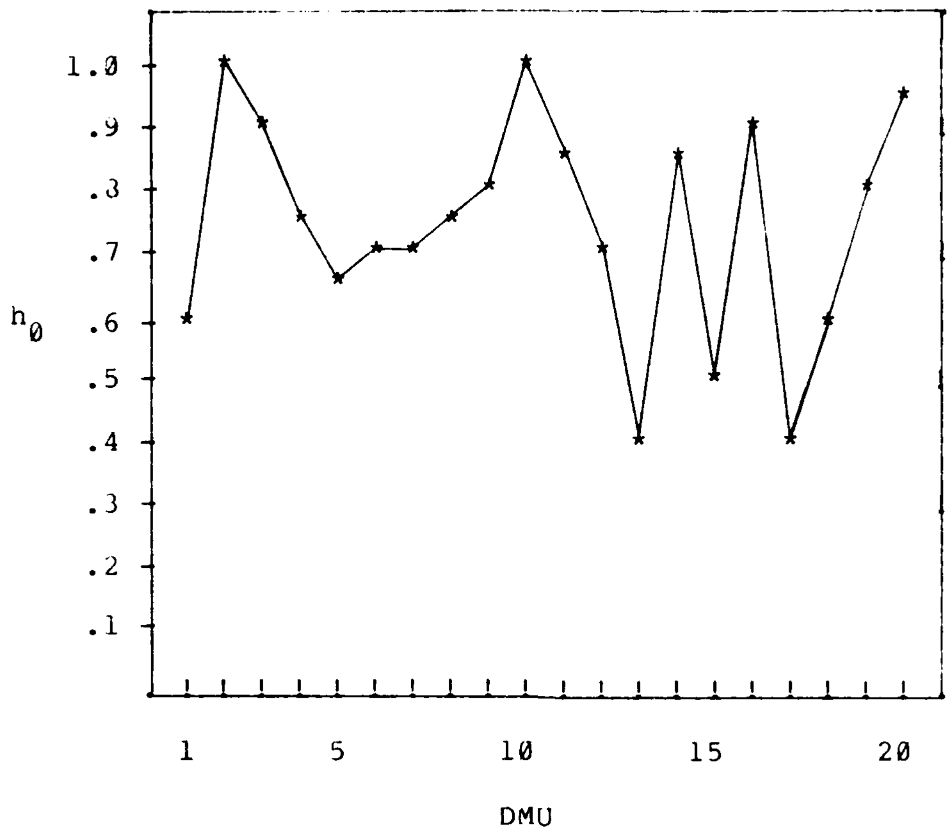


Figure 4. DEA Efficiency Values (First DEA Model)

these inputs produce? Another look at the output variables reveals a possible answer. The two outputs, quality audit findings and aircraft delivered on-time, fail to include the aircraft not produced on-time. However, these late-delivered aircraft consume inputs just the same as on-time delivered aircraft consume inputs. It follows that the DEA model should include total aircraft produced whether on-time or late. The second DEA model includes total aircraft produced as a third output variable. This DEA model preserves management's objective to produce the aircraft

on-time by including both on-time deliveries and total aircraft production as outputs.

The second DEA model (sample two in Appendix C) using the additional output yielded the efficinecy measures shown in Table II. With the added output variable, four DMUs attained 100 percent relative efficiency and 12 of the 20 DMUs reflect higher DEA efficiencies than the previous analysis. The second DEA model indicates the Aircraft Division operated more efficiently during October 1983 to May 1985 than the first DEA model indicated. For a look at possible trends, Figure 5 shows a graph of the efficiencies from the second DEA model. It appears the fluctuations diminished somewhat, however, they remain steep.

In addition to the matching problem discussed above, a second possible cause for the persistent steep fluctuations of the DEA efficiencies could be due to "carryover" effects inherent in this data. Carryover in this case implies the observations for a particular month may not occur independently and randomly but instead depend upon observations from previous time periods. For example, say in month one only two of three aircraft are produced on-time, and in month two four aircraft are scheduled for completion. If the late aircraft from month one is completed in month two, then month two scheduled production increases to five and the aircraft produced late in month one is now an on-time delivery in month two. This example

Table II

DEA Efficiency Values (Second DEA Model)

Month	DMU	Old Efficiency	Revised Efficiency
OCT 1983	1	.619	.834
NOV	2	1.000	1.000
DEC	3	.905	1.000
JAN 1984	4	.741	1.000
FEB	5	.646	.743
MAR	6	.685	.909
APR	7	.724	.724
MAY	8	.770	.770
JUN	9	.796	.796
JUL	10	1.000	1.000
AUG	11	.856	.856
SEP	12	.688	.748
OCT	13	.413	.527
NOV	14	.833	.833
DEC	15	.494	.604
JAN 1985	16	.899	1.000
FEB	17	.405	.863
MAR	18	.581	.678
APR	19	.819	.945
MAY	20	.929	.929

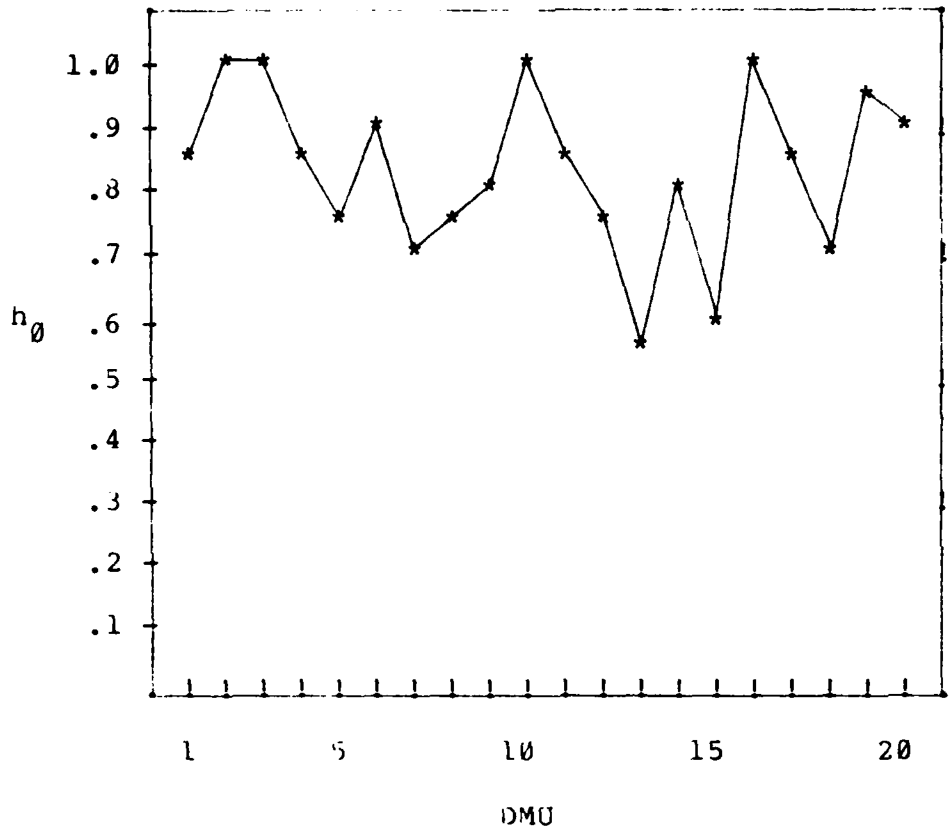


Figure 5. DEA Efficiency Values (Second DEA Model)

illustrates how the production schedules are dependent upon previous periods or one month's production rate may "carryover" into the next month.

The author thought combining the monthly data into quarters may offset this carryover effect. This assumes production fluctuations causing the carryover are less apparent between quarters rather than between months since there are fewer opportunities for carryover. The third DEA model (sample three in Appendix C) uses the quarterly

observations. Month 21 was estimated using the arithmetic mean of the 20 months of inputs (direct labor, material dollars, overtime hours) and the 20 months of outputs (quality audit findings, aircraft produced on-time, total aircraft produced) so that seven quarters were now in the data base (where each quarter represents one DMU).

Table III shows the results of the third DEA model including both efficiency values and slack values. Out of seven DMUs, five rated 100 percent relative efficient. This indicates the Aircraft Division, on a quarterly basis from October 1983 to November 1984 and from April 1985 to June 1985 (estimated), operated at an efficient level given the inputs and outputs selected and the decision making units (= time periods). The graph of the seven DEA efficiency values in Figure 6 shows fewer fluctuations than previous DEA models. This shows quarterly data reduced the perturbations monthly data created. However, one would expect this to happen because the model tested only a few observations. A rule of thumb when using DEA is that there be two DMUs for each input/output variable used in the model. Otherwise there is a tendency for all DMUs to be reported as efficient. Hence, it would be conjecture at best to analyze for possible trends with only seven observations. A longer time period must be studied.

DEA has been criticized for not incorporating slack values into the efficiency measure, h_0^* (7, 11).

Table III

DEA Efficiency and Slack Values

DMU	h_0	SPQA	SPOD	SPTP	SNDL	SNM	SNOT
1	1.00	0	0.0	0	0	0	0
2	1.00	0	0.0	0	0	0	0
3	1.00	0	0.0	0	0	0	0
4	1.00	0	0.0	0	0	0	0
5	0.88	0	0.6	0	64508	429293	0
6	0.95	0	2.9	0	0	158043	17366
7	1.00	0	0.0	0	0	0	0

SPQA = Positive slack of output variable -- Ready-For-Delivery audit findings.

SPOD = Positive slack of output variable -- on-time aircraft deliveries.

SPTP = Positive slack of output variable -- total aircraft produced.

SNDL = Negative slack of input variable -- direct labor hours.

SNM = Negative slack of input variable -- total material dollars.

SNOT = Negative slack of input variable -- overtime hours.

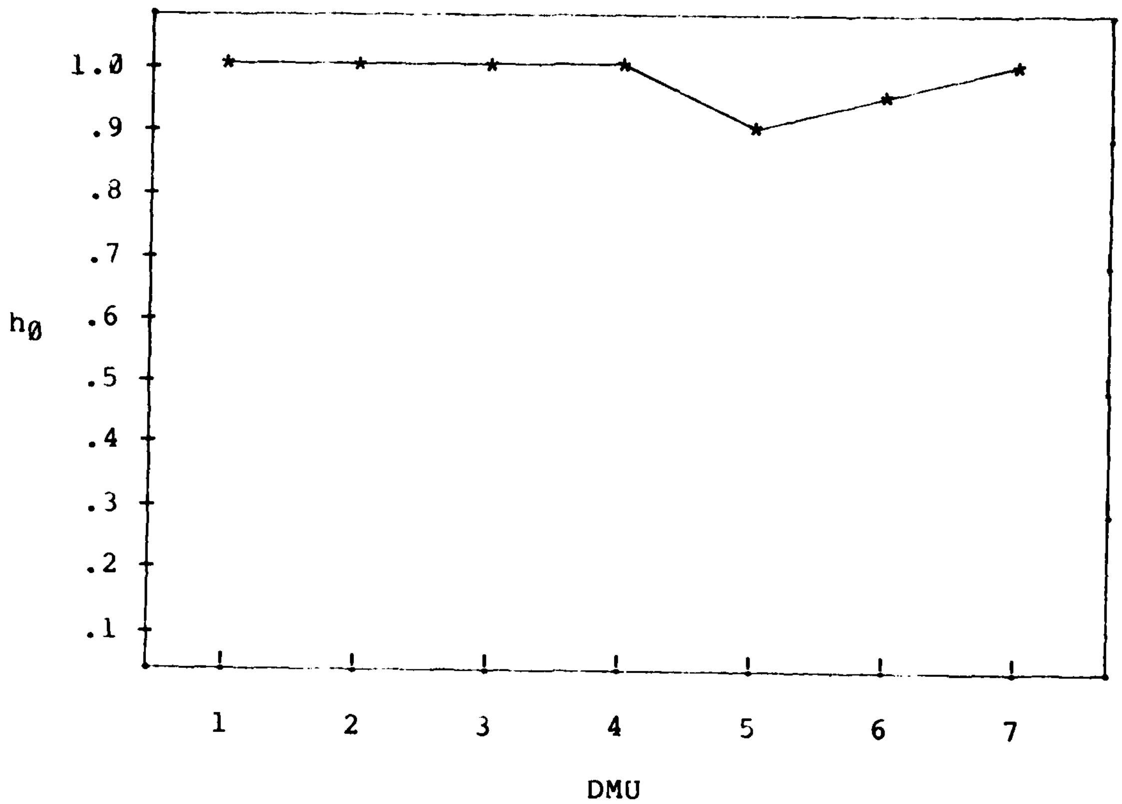


Figure 6. DEA Efficiency Values (Third DEA Model)

Specifically, one of the criticisms of DEA is that inefficiencies in the data are reflected in two parts as can be seen in the DEA linear programming equation (8). Part of the inefficiency is reflected in the θ^* value and part in the slack values, S_r^+ and S_i^-. When the non-Archimedian conditions are fulfilled, $h_0^* = \theta^*$, the efficiencies reflected in the slack values are not reflected in h_0^*. Thus, when ranking DMUs based on the h_0^* value or performing statistical analysis there is a chance for error due to not including inefficiencies reflected in the slack values.

Clark (12) proposed a variant of DEA called Constrained Facet Analysis (CFA) for correcting this shortcoming. However, his approach projects efficient DMUs outside the range of data, shows some instability in the results, and has other limitations as discussed by Bowlin (3:63).

Bowlin (4) proposed a solution to this problem with DEA by computing an average efficiency which incorporates inefficiencies reflected in the slack values, keeps projections of efficient DMUs within the range of data, and uses the output from DEA. This allows a more reliable ranking of DMUs based on their efficiency and provides a single efficiency value for accomplishing statistical analyses.

Bowlin's approach builds upon Charnes, Cooper, and Rhodes (10) technique for computing efficient input and output levels for an inefficient DMU. Charnes, Cooper, and Rhodes compute efficient input/output levels using the following equations.

$$\hat{X}_i^* = X_i h_0^* - S_i^{-*} \tag{11}$$

$$\hat{Y}_r^* = Y_r + S_r^{+*} \tag{12}$$

Thus, $\hat{X}_i^*$ and $\hat{Y}_r^*$ are the input and output levels that should have been achieved by the inefficient DMU.

Figure 7 shows the calculations of average input

DMU 5

Efficient input level

(actual input level x efficiency) - slack =

efficient level of input

$$(X_i \times h_0^*) - S_i^{-*} = \hat{X}_i^* \qquad (11)$$

Direct labor hours:

$$(676175 \times .881) - 64508 = 531202 \qquad (13)$$

Material dollars:

$$(4887598 \times .881) - 429293 = 3876680 \qquad (14)$$

Overtime hours:

$$(50793 \times .881) - 0 = 44748 \qquad (15)$$

Input efficiency

$$\frac{\text{efficient level}}{\text{actual level}} = \text{input efficiency}$$

$$\text{Direct labor: } \frac{531202}{676175} = .786 \qquad (16)$$

$$\text{Material: } \frac{3976680}{4887598} = .793 \qquad (17)$$

$$\text{Overtime: } \frac{44748}{50793} = .881 \qquad (18)$$

Average input efficiency:

$$\frac{.786 + .793 + .881}{3} = .820 \qquad (19)$$

Figure 7. DMU 5 Input Efficiencies

efficiencies for DMU five from the DEA results of quarterly data using Bowlin's approach. To calculate efficient input levels [equation (11)], the actual input level is multiplied by the relative efficiency of the DMU ($h_{\emptyset}^{*}$), and if a slack value exists for that input, the slack is subtracted from the product of actual input x efficiency. For DMU five the actual direct labor hours were 676175 hours, the relative efficiency is .881, and the slack is 64508 hours leaving the efficient level of direct labor at 531202 hours in equation (13). This indicates that based on the comparison of itself to the other six DMUs, DMU five could have used 531202 direct labor hours to produce the same level of output. Figure 7 includes similar calculations for the other inputs--material dollars and overtime hours--in equations (14) and (15), respectively.

Having calculated the efficient input level for each variable, the efficiency for each individual input is the ratio of the efficient level of input over the actual input level as shown in equations (16), (17), and (18). Where the DEA efficiency ($h_{\emptyset}^{*}$) applies to the DMU as a whole, the input efficiency applies to a particular input for a DMU. For direct labor hours used in DMU five the input efficiency is .786 (or 78.6 percent efficient); for material dollars the input efficiency is .793; and for overtime hours the input efficiency is .881.

The last calculation, average input efficiency [equation (19)], simply takes the arithmetic mean of the individual input efficiencies. For DMU five the average input efficiency is .82. Conversely, for DMU five the average input inefficiency is .18 (1 - .82). For ranking and statistical analysis purposes, this average input efficiency provides a rating which encompasses both the DMU's efficiency, h_0^*, and its input slack value, S_i^{-*}. The adjusted efficiency measure did not account for output slack values because none exsisted. However, if they did exist, an overall measure of average efficiency could be computed. Further analysis using the average input efficiency or average overall efficiency was not pursued due to the difficulty of interpreting DEA results for monthly data caused by steep fluctuations and for quarterly data due to the low number of data points.

This concludes the presentation of Data Envelopment Analysis results and analysis. Discussion now turns to regression analysis.

Regression Results and Analysis. This regression analysis provides information concerning which independcent variable or variables are significant as predictors of the dependent variable. The regression analyses use total aircraft produced as the dependent variable in place of on-time deliveries. As in DEA, the purpose for this change

from the initial course of action is to use a dependent variable which more fully and properly represents output produced from the inputs. This change better serves the purpose of this regression analysis which is to determine which independent variables best predict the number of total aircraft deliveries so that a model can be developed to measure productivity. The results of the regression calculations are presented in Tables IV and V. Table IV shows the 12 regression analyses for 20 months of data with the dependent variable compared against various combinations of independent variables. Appendix C contains a sample of this regression program (sample four). Table V shows the results from 12 regression analyses using seven quarters of data.

Tables IV and V show the independent variables, dependent variable, R-Square value, and beta significance level for each regression analysis. Each regression analysis uses the same dependent variable, total aircraft produced (TOTDEL). The R-Square, or coefficient of determination, measures the percent of variance (the difference between the actual and predicted value of the dependent variable) explained by the regression equation. The actual regression equations are not necessary for this analysis. Generally, the closer the coefficient of determination is to 1.00, the better predictor it is; the

Table IV

Regression Results for 20 Months

Independent Variables	Dependent Variable	R Square	Beta Sig Level
1. DLHRS	TOTDEL	.27	.02
2. OVTHRS	TOTDEL	.06	.31
3. MATDOL	TOTDEL	.02	.55
4. HRS	TOTDEL	.26	.02
5. MATDOL HRS	TOTDEL	.27	.60 .03
6. OVTHRS MATDOL DLHRS	TOTDEL	.31	.95 .38 .04
7. MATDOL DLHRS	TOTDEL	.31	.33 .02
8. OVTHRS DLHRS	TOTDEL	.27	.70 .04
9. OVTHRS MATDOL	TOTDEL	.08	.30 .51
10. LNOVT LNMAT LNDLH	TOTDEL	.32	.97 .36 .04
11. LNMAT LNHRS	TOTDEL	.28	.58 .02
12. LNHRS	TOTDEL	.27	.02

Table IV (continued)

Regression Results For 20 Months

DLHRS	= Direct labor hours
OVTHRS	= Overtime hours
MATDOL	= Material dollars
HRS	= (DLHRS + OVTHRS)
LNOVT	= Natural log of OVTHRS
LNMAT	= Natural log of MATDOL
LNDLH	= Natural log of DLHRS
LNHRS	= Natural log of HRS
TOTDEL	= Total aircraft produced

closer the coefficient of determination is to 0.00, the poorer predictor it is.

The significance level shown in Tables IV and V is the confidence level for the calculated F values of each regression coefficient or beta. Interpretations of the significance level can best be explained using an example. Take, for instance, independent variable 1, DLHRS, from Table IV. If we desire to test to see if the slope of the regression line is 0, that is, test whether beta is equal to 0 or not equal to 0, then the null hypothesis (H_0) is $\beta = 0$ and the alternative hypothesis (H_a) is $\beta \neq 0$. From Table IV the significance level is .02 which means there is 98 percent (1 - .02) confidence that β is not equal to 0. For a significance test of the beta values, the author selected the .05 level. In this example, the independent

Table V

Regression Results for 7 Quarters

Independent Variables	Dependent Variable	R Square	Beta Sig Level
1. DLHRS	TOTDEL	.56	.05
2. OVTHRS	TOTDEL	.24	.26
3. MATDOL	TOTDEL	.17	.35
4. HRS	TOTDEL	.77	.01
5. MATDOL HRS	TOTDEL	.77	.99 .03
6. OVTHRS DLHRS MATDOL	TOTDEL	.82	.45 .14 .44
7. MATDOL DLHRS	TOTDEL	.78	.11 .03
8. OVTHRS DLHRS	TOTDEL	.78	.11 .04
9. OVTHRS MATDOL	TOTDEL	.60	.11 .13
10. LNOVT LNDLH LNMAT	TOTDEL	.81	.37 .22 .66
11. LNMAT LNHRS	TOTDEL	.77	.93 .03
12. LNHRS	TOTDEL	.77	.01

variable has a significance level of .02 and the null hypothesis is rejected. Therefore, testing the null hypothesis, H_0: $\beta = 0$ and the alternative hypothesis H_a: $\beta \neq 0$, significance levels (from Tables IV and V) less than .05 indicate a rejection of H_0 or an acceptance that there is a relationship between the independent and dependent variables while significance levels greater than .05 indicate failure to reject H_0. Failure to reject the null hypothesis means it cannot be ruled out that beta equals 0. In the cases where the regression equation has more than one beta (i.e. more than one variable), if for one of the independent variables the null hypothesis cannot be rejected, then the entire equation cannot be used as a predictor of the dependent variable.

The regression results of 20 months of data (Table IV) have coefficients of determination ranging from .02 to .32. R-Square values this low is evidence that no independent variable or combination of variables is a good predictor of the dependent variable and precludes discussing the significance of the individual independent variables.

These low coefficient of determination values also indicate that possibly one of the assumptions of DEA--an increase in input should result in an increase in output--is violated and our DEA model is thus suspect. However, monthly data could have a significant amount of random variations in it accounting for low R-Square values.

Experts at the ALC are convinced the inputs and outputs selected are valid for DEA.

The regression results of the quarterly data (Table V) provide different interpretations. These results show coefficients of determination ranging from .17 to .82 . Since R-Square values closer to 1.00 are better predictors, the author selected regressions 4, 5, 6, 7, 8, 10, 11 and 12 for further investigation. Significance tests of the beta values for regressions 6 and 10 show none of the variables are significant (null hypothesis cannot be rejected). In regressions 7 and 8 only direct labor hours (DLHRS) is significant while the second variable is not, consequently the regression equation is not a predictor of the dependent variable. Similarly, total labor hours (HRS) in regression 5 and the natural logarithm of total labor hours (LNHRS) in regression 11 are significant but the second variable in each equation cannot reject the null hypothesis. Finally, total labor hour (HRS) in regression 4 and the natural log of total labor hours (LNHRS) in regression 12 both reject the null hypothesis with a .01 significance level. Regression 4 and 12 explain 77 percent of variance in the residuals and have coefficients not equal to 0.00. This indicates perhaps total labor hours (direct labor + overtime) may be a predictor of the quantity of total aircraft produced. It also supports Aircraft Division management's position of the relationship between the labor hours and total aircraft produced.

Before drawing conclusions from regression analysis, underlying assumptions must be made about the observations. The next section discusses the limitations when making assumptions about the data base used in the this research.

Regression Validation

The limitations inherent in the data base precludes the development of a valid regression model which measures the productivity of the San Antonio ALC. Eventhough transforming monthly data into quarterly data provided "better" regression results, two problems persist because the data is time series. The first problem is that successive observations are not independent because of the "carryover" effect discussed in the DEA analysis section. Observations must be independent to perform a valid regression analysis. The second problem is "the effect of the relationship of long-term trend upon the correlation coefficient" (24:445). No meaningful regression analysis can be conducted further without correcting these problems. To develop a regression model that measures productivity using this time series data would be invalid. Therefore no efficiency measures as proposed in the methodology (Chapter III) was computed.

DEA Validation

In order for the DEA portion of this research to be valid, the four criteria discussed in Chapter III had to be met. Those criteria are:

1. The inputs and outputs should be inclusive of all aircraft depot maintenance activities. The measures should "fully and properly" represent the maintenance activity.

The author ensured this criteria be met by visiting the San Antonio ALC personally and along with Aircraft Division management, select the proper inputs and outputs.

2. The inputs and outputs should be related such that an increase (decrease) in an input can be expected to cause an increase (decrease) in an output.

The regression analysis verifies this criterion. The coefficients of correlation between the independent variables and each output (dependent variable) were positive indicating a direct relationship between the sets of variables, although not a very significant one in some cases (Table VI). In addition, the DEA model uses the reciprocal of the Ready-For-Delivery audit findings so that this criterion is not violated.

3. Inputs and outputs should exist in positive amounts. All inputs and outputs met this criterion.

Table VI

Coefficients of Correlation
(Using Quarterly Data)

Independent Variable	Dependent Variables		
	Total Production	On-time Deliveries	RFD Audit Findings
Direct labor	.75	.87	.59
Material	.42	.67	.57
Overtime	.49	.06	.07

4. The data should be documented so that it cannot be manipulated so as to influence the results of the analysis.

All data was documented and the sources are discussed earlier in this chapter.

Given that this research adheres to these four criterion, the Data Envelopment Analysis is considered valid.

Summary

This chapter covered four major areas: the data base for this thesis, the results and analysis of regression and DEA, and a discussion of regression and DEA validation. This chapter addressed research objectives three, four, and five.

3. Develop a DEA model for measuring productive efficiency of the Aircraft Division at the San Antonio ALC.

4. Develop a regression model for measuring productive efficiency of the Aircraft Division at the San Antonio ALC.

5. Demonstrate the validity of the DEA and regression models as a measures of productive efficiency.

The next chapter presents the conclusions and recommendations for further research.

V. Conclusions and Recommendations

Conclusions

Regression. Given the small number of observations in the data base and its time series nature, a regression model measuring productivity of the San Antonio ALC could not be formulated. The regression results and analysis appear to indicate that perhaps the independent variable, total labor hours (direct labor hours + overtime hours), may be a predictor of total aircraft produced. However, further research is needed to build evidence to support this relationship whereupon a regression model may be developed.

DEA. Results of this thesis are suspect due to limited availability of data. Monthly data had wide variations and quarterly data had too few observations (degrees of freedom) making it impossible to draw unqualified conclusions. Aside from this fact, based on the DEA model of monthly data, it might be concluded that during the months November 1983, December 1983, July 1984, and January 1985 (which correspond to DMUs 2, 3, 10, and 16) the Aircraft Division operated at 100 percent relative efficiency. However, the data are time series and thus

random fluctuations occur. Lumping the data into quarters reduced the seasonality and "carryover" present in an aircraft depot maintenance operation. When months are transformed to quarters, DEA showed the Aircraft Division operated at 100 percent relative efficiency in DMUs 1, 2, 3, 4, and 7 [October 1983 - November 1984 and April 1985 - June 1985 (estimated)]. The relative efficiency during quarters five and six was .88 and .95, respectively.

The input efficiency analysis for DMU 5 showed, at a minimum, the Aircraft Division could have reduced inputs by 12 percent and still produced the same level of output. (Refer to Table III.) It can be concluded from the DEA results that something happened in the Aircraft Division in the October 1984 - March 1985 time-frame (DMUs five and six) which caused efficiency to drop below 100 percent. Relative to the other five quarters, the Aircraft Division could have used fewer inputs to produce the same output achieved. An investigation into why this occurred, whether the cause was exogenous or endogenous to Aircraft Division management, would be a worthwhile effort but beyond the scope of this thesis.

DEA Summary. Charnes, Cooper, and Rhodes (10) designed DEA as a method of comparing similar organizations, or decision making units, to derive a measure of relative efficiency. This thesis did not

compare similar organizations, rather it compared a single organization to itself over time. This research can be labeled "prototypic" in the sense that it tested the possible use of Data Envelopment Analysis as a means of measuring productivity (efficiency) over time by using "real world" data. Prototypic testing is the step between mathematical development of the model and general application of the model.

Recommendations

This research has opened several areas for further research. Six recommendations for additional studies are listed below.

1. This study did not result in firm conclusions using DEA because of the extremely limited data base. Further research could be conducted on DEA using a more extensive data base. Additionally, when determining inputs and outputs for DEA, the researcher should verify the size of the data base for each variable before selecting it for use in the model.

2. This research showed fluctuations in productivity of the Aircraft Division at the San Antonio ALC from October 1983 to May 1985. A study could uncover why these fluctuations occurred and what might be done in the future to enhance more productive behavior.

3. Research could focus on a particular AFLC policy implemented at an Air Logistics Center intended to improve productivity. Calculating DEA efficiency measures using data accumulated before and after policy implementation may reflect the effectiveness of productivity improvement policies. The author investigated productivity improvement policies implemented in the depot during October 1983 to May 1985 but found none that specifically changed aircraft maintenance operations drastically enough for the data to reflect a change in productivity (efficiency).

4. During the course of this work, management personnel at the San Antonio ALC, Aircraft Division surfaced differences between their activity and that of other ALCs. For example, not all ALCs maintain the same type of aircraft. Another area of research would be to define and investigate these differences and determine their impact on the validity of comparing different ALCs with the current productivity measure (OPMD) or any alternative productivity measures.

5. All is not lost when only time series data exits for regression analysis. One could continue researching the application of a regression model as a measure of productivity. Techniques such as correlation of first differences, correlation of cycles, and time as a separate independent variable can be used to study time series data (24:446). However, to pursue regression as a model

measuring productivity the researcher must locate a large enough data base in order to adhere to the assumptions necessary to validate regression analysis.

6. The last area of recommended research pertains to the future and, when addressed, would answer research objective six. Research objective six asks, "What is Air Force Logistics Command management's perception of DEA or regression analysis as a technique for measuring productivity?" Some researchers solicit management's perception of a particular study then consider the managers' opinion a validation of the study. On the contrary, this thesis has pointed out for DEA or regression analysis to be used as techniques for measuring productivity, a more extensive data base must be available for inputs and outputs. These techniques must then be "test marketed" long enough for managers to develop a perception of DEA or regression as productivity measures. Only then can management's perceptions be surveyed and constructive conclusions be drawn.

Appendix A: Data Base

Inputs

Month	Direct labor hours	Material Dollars*	Overtime hours
Oct 1983	239056	1551977	28422
Nov	226273	1566519	22826
Dec	212516	1124035	22826
Jan 1984	234548	1742426	21435
Feb	236324	1912879	28834
Mar	251283	2325365	24496
Apr	242984	2117390	18593
May	256569	2239905	19349
Jun	234018	2219085	12779
Jul	226143	1494152	14066
Aug	264103	2143479	21646
Sep	220493	1959642	17149
Oct	257647	1725849	21022
Nov	218646	1478763	14122
Dec	199882	1879736	15649
Jan 1985	230686	1900704	24939
Feb	222393	1299409	33422
Mar	250253	2180550	39338
Apr	239319	1871945	25263
May	247952	1842443	33842

* Not adjusted for inflation

Outputs

Month	Ready-For-Delivery Audit Findings	On-time Deliveries	Total Aircraft Production
Oct 1983	353	3	5
Nov	112	2	3
Dec	564	4	5
Jan 1984	755	5	6
Feb	562	4	5
Mar	819	5	7
Apr	700	5	5
May	1013	6	6
Jun	664	4	4
Jul	1091	7	7
Aug	1110	7	7
Sep	260	2	3
Oct	1112	3	4
Nov	692	5	5
Dec	507	2	3
Jan 1985	662	6	7
Feb	979	2	5
Mar	719	4	5
Apr	1108	6	7
May	873	7	7

Appendix B: Inflation Indexes (17)

Month	Index*
Oct 1983	346.1
Nov	346.1
Dec	346.1
Jan 1984	349.3
Feb	351.7
Mar	351.7
Apr	351.7
May	351.7
Jun	351.7
Jul	351.7
Aug	351.7
Sep	357.4
Oct	357.4
Nov	361.4
Dec	361.4
Jan 1985	361.4
Feb	361.4
Mar	361.4
Apr	367.7
May	367.7**

* Index base = 12/68 = 100
** Projection assuming no change in inflation from April.

AD-A162 308 MEASURING PRODUCTIVITY OF DEPOT-LEVEL AIRCRAFT MAINTENANCE IN THE AIR FOR (U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST R W LOWRY 2/2

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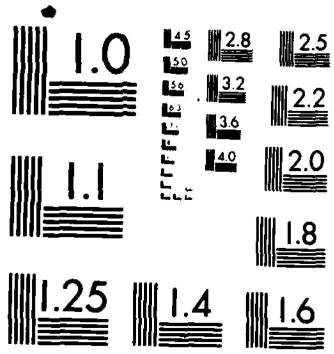

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Appendix C: Computer Program Samples

Sample 1: MPOS program with 5 variables using 20 DMUs.

```
REGULAR
TITLE
DMU 1
VARIABLES
T L1 TO L20 SPQA SPOD SNDL SNM SNOT
MINIMIZE
T
CONSTRAINTS
1.  .00283L1 + .00893L2 + .00177L3 + .00132L4 + .00178L5 +
    .00122L6 + .00143L7 + .00099L8 + .00151L9 + .00092L10 +
    .0009L11 + .00385L12 + .0009L13 + .00145L14 + .00197L15
    + .00151L16 + .00102L17 + .00139L18 +.0009L19 +
    .00115L20 - SPQA = .00283
2.  3L1 + 2L2 + 4L3 + 5L4 + 4L5 + 5L6 + 5L7 + 6L8 + 4L9 +
    7L10 + 7L11 + 2L12 + 3L13 + 5L14 + 2L15 + 6L16 + 2L17 +
    4L18 + 6L19 + 7L20 - SPOD = 3
3.  239056T - 239056L1 - 226273L2 - 212516L3 - 234548L4 -
    236324L5 - 251283L6 - 242984L7 - 256569L8 - 234018L9 -
    226143L10 - 264103L11 - 220493L12 - 257647L13 -
    218646L14 - 199882L15 - 230686L16 - 222393L17 -
    250253L18 - 239319L19 - 247954L20 - SNDL = 0
4.  1551977T - 1551977L1 - 1566519L2 - 1124035L3 -
    1726463L4 - 1882421L5 - 2288339L6 - 2083675L7 -
    2204240L8 - 2183751L9 - 1494152L10 - 2109349L11 -
    1897683L12 - 1671282L13 - 1416159L14 - 1800157L15 -
    1820237L16 - 1244398L17 - 2088236L18 - 1761980L19 -
    1734211L20 - SNM = 0
5.  28422T - 28422L1 - 22826L2 - 22846L3 - 21435L4 -
    28834L5 - 24496L6 - 18593L7 - 19349L8 - 12779L9 -
    14066L10 - 21646L11 - 17149L12 - 21022L13 - 14122L14 -
    15649L15 - 24939L16 - 33422L17 - 39338L18 - 25263L19
    - 33842L20 - SNOT = 0
COLUMN 128
OPTIMIZE
STOP
```

Sample 2: MPOS program with 6 variables using 20 DMUs.

```
REGULAR
TITLE
DMU 1
VARIABLES
T L1 TO L20 SPQA SPOD SPTP SNDL SNM SNOT
MINIMIZE
T
CONSTRAINTS
1.  .00283L1 + .00893L2 + .00177L3 + .00132L4 + .00178L5 +
    .00122L6 + .00143L7 + .00099L8 + .00151L9 + .00092L10 +
    .0009L11 + .00385L12 + .0009L13 + .00145L14 + .00197L15
    + .00151L16 + .00102L17 + .00139L18 +.0009L19 +
    .00115L20 - SPQA = .00283
2.  3L1 + 2L2 + 4L3 + 5L4 + 4L5 + 5L6 + 5L7 + 6L8 + 4L9 +
    7L10 + 7L11 + 2L12 + 3L13 + 5L14 + 2L15 + 6L16 + 2L17 +
    4L18 + 6L19 + 7L20 - SPOD = 3
3.  5L1 + 3L2 + 5L3 + 6L4 + 5L5 + 7L6 + 5L7 + 6L8 + 4L9 +
    7L10 + 7L11 + 3L12 + 4L13 + 5L14 + 3L15 + 7L16 + 5L17 +
    5L18 + 7L19 + 7L20 - SPTP = 5
4.  239056T - 239056L1 - 226273L2 - 212516L3 - 234548L4 -
    236324L5 - 251283L6 - 242984L7 - 256569L8 - 234018L9 -
    226143L10 - 264103L11 - 220493L12 - 257647L13 -
    218646L14 - 199882L15 - 230686L16 - 222393L17 -
    250253L18 - 239319L19 - 247954L20 - SNDL = 0
5.  1551977T - 1551977L1 - 1566519L2 - 1124035L3 -
    1726463L4 - 1882421L5 - 2288339L6 - 2083675L7 -
    2204240L8 - 2183751L9 - 1494152L10 - 2109349L11 -
    1897683L12 - 1671282L13 - 1416159L14 - 1800157L15 -
    1820237L16 - 1244398L17 - 2088236L18 - 1761980L19 -
    1734211L20 - SNM = 0
6.  28422T - 28422L1 - 22826L2 - 22846L3 - 21435L4 -
    28834L5 - 24496L6 - 18593L7 - 19349L8 - 12779L9 -
    14066L10 - 21646L11 - 17149L12 - 21022L13 - 14122L14 -
    15649L15 - 24939L16 - 33422L17 - 39338L18 - 25263L19
    - 33842L20 - SNOT = 0
COLUMN 128
OPTIMIZE
STOP
```

Sample 3: MPOS program with 6 variables using 7 DMUs.

```
REGULAR
TITLE
DMU 71 -- A DEA OF QUARTERLY DATA
VARIABLES
T L1 TO L7 SPQA SPOD SPTP SNDL SNM SNOT
MINIMIZE
T
CONSTRAINTS
1.  .000972L1 + .000468L2 + .000421L3 + .000406L4 +
    .000433L5 + .000424L6 + .000368L7 - SPQA = .000972
2.  9L1 + 14L2 + 15L3 + 16L4 + 10L5 + 12L6 + 17L7 - SPOD =
    9
3.  13L1 + 18L2 + 15L3 + 17L4 + 12L5 + 17L6 + 19L7 - SPTP =
    13
4.  677845T - 677845L1 - 722155L2 - 733571L3 - 710739L4 -
    676175L5 - 703332L6 - 722825L7 - SNDL = 0
5.  4242531T - 4242531L1 - 5897223L2 - 6471666L3 -
    5477393L4 - 4887598L5 - 5152871L6 - 5217573L7 - SNM = 0
6.  74094T - 74094L1 - 74765L2 - 50721L3 - 52861L4 -
    50793L5 - 97699L6 - 82107L7 - SNOT = 0
COLUMN 128
OPTIMIZE
STOP
```

Sample 4: SPSS program of 12 regressions.

```
RUN NAME          REGRESSION NO. 44 -- 12 REGRESSIONS WITH
                  TOTDEL
                      -----  MONTHLY  DATA  -----
PRINT BACK        CONTROL
VARIABLE LIST     TOTDEL,DLHRS,MATDOL,OVTHRS
INPUT MEDIUM      CARD
N OF CASES        20
INPUT FORMAT      FIXED(F4.0,F7.0,F8.0,F6.0)
COMPUTE           HRS=DLHRS+OVTHRS
COMPUTE           LNDLH=LN(DLHRS)
COMPUTE           LNMAT=LN(MATDOL)
COMPUTE           LNOVT=LN(OVTHRS)
COMPUTE           LNHRS=LN(HRS)
VAR LABELS        TOTDEL,TOTAL AIRCRAFT DELIVERIES/DLHRS,
                  DIRECT LABOR ACTUAL HOURS/MATDOL,MATERIAL
                  DOLLARS/
                  OVTHRS,OVERTIME HOURS/
                  HRS,TOTAL DIRECT LABOR HOURS/
                  LNDLH,NATURAL LOG OF DLHRS/
                  LNMAT,NATURAL LOG OF MATDOL/
                  LNOVT,NATURAL LOG OF OVTHRS/
                  LNHRS,NATURAL LOG OF HRS/
NEW REGRESSION DESCRIPTIVES/
                  VARIABLES=TOTDEL,DLHRS/
                      STATISTICS= R COEFF LABEL F/
                      DEPENDENT=TOTDEL/
                      ENTER/
                  VARIABLES=TOTDEL,OVTHRS/
                      STATISTICS = R COEFF LABEL F/
                      DEPENDENT=TOTDEL/
                      ENTER/
                  VARIABLES=TOTDEL,MATDOL/
                      STATISTICS=R COEFF LABEL F /
                      DEPENDENT=TOTDEL/
                      ENTER/
                  VARIABLES=TOTDEL,HRS/
                      STATISTICS=R COEFF LABEL F/
                      DEPENDENT=TOTDEL/
                      ENTER/
                  VARIABLES=TOTDEL,HRS,MATDOL/
                      STATISTICS=R COEFF LABEL F/
                      DEPENDENT=TOTDEL/
                      ENTER/
                  VARIABLES=TOTDEL,DLHRS,MATDOL,OVTHRS/
                      STATISTICS=R COEFF LABEL F/
                      DEPENDENT=TOTDEL/
                      ENTER/
```

```
          VARIABLES=TOTDEL,DLHRS,MATDOL/
              STATISTICS=R COEFF LABEL F/
              DEPENDENT=TOTDEL/
              ENTER/
          VARIABLES=TOTDEL,DLHRS,OVTHRS/
              STATISTICS=R COEFF LABEL F/
              DEPENDENT=TOTDEL/
              ENTER/
          VARIABLES=TOTDEL,MATDOL,OVTHRS/
              STATISTICS=R COEFF LABEL F/
              DEPENDENT=TOTDEL/
              ENTER/
          VARIABLES=TOTDEL,LNDLH,LNMAT,LNOVT/
              STATISTICS=R COEFF LABEL F/
              DEPENDENT=TOTDEL/
              ENTER/
          VARIABLES=TOTDEL,LNHRS,LNMAT/
              STATISTICS=R COEFF LABEL F/
              DEPENDENT=TOTDEL/
              ENTER/
          VARIABLES=TOTDEL,LNHRS/
              STATISTICS=R COEFF LABEL F/
              DEPENDENT=TOTDEL/
              ENTER/
READ INPUT DATA
FINISH
```

Appendix D: Slack Values From First DEA Model

DMU	SPQA	SPOD	SNDL	SNM	SNOT
1	0	0.0	5617	0	6278
2	0	0.0	0	0	0
3	0	0.0	39924	0	9941
4	0	0.0	0	137430	4406
5	0	0.0	0	216627	7861
6	0	0.0	0	450693	5502
7	0	0.0	0	364342	1739
8	0	0.0	0	417852	2408
9	0	0.0	38722	783424	0
10	0	0.0	0	0	0
11	0	0.0	0	341241	4469
12	0	0.0	20233	450151	0
13	0	0.0	0	5547	1552
14	0	0.0	5874	60723	0
15	0	0.0	2193	276338	0
16	0	0.0	0	332401	8788
17	0	0.0	11367	0	7879
18	0	0.0	0	299006	12934
19	0	0.0	0	237089	8383
20	0	0.0	0	187858	16886

SPQA = Positive slack of output variable -- Ready-For-Delivery audit findings.

SPOD = Positive slack of output va iable -- on-time aircraft deliveries.

SNDL = Negative slack of input variable -- direct labor hours.

SNM = Negative slack of input variable -- total material dollars.

SNOT = Negative slack of input variable -- overtime hours.

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This investigation measures the productivity (efficiency) of the San Antonio Air Logistics Center, Aircraft Division between October 1983 to May 1985. This study consisted of developing a multiple input, multiple output Data Envelopment Analysis (DEA) model and a multiple input single output regression model to measure productive efficiency. The data base consisted of time series data drawing only from the Aircraft Division.

A three input, three output DEA model was developed to analyze 20 months of data. The data was further grouped into quarters to offset the fluctuations inherent in monthly data. The inputs for the DEA model are direct labor actual hours, total material dollars, and overtime hours. The outputs are aircraft delivered on-time, total aircraft produced, and the number of deficiencies found during quality audit inspections.

The regression analysis studied the same inputs but used only total aircraft produced as the dependent variable. The interpretations from the regression analysis are limited because the observations are time series and few in number.

The results of the DEA models showed the Aircraft Division to be 100 percent relative efficient during four of the 20 months studied as well as five out of the seven quarters. Extensive interpretations of the DEA results was restricted due to having data for only 20 months.

The regression analysis only showed that perhaps total labor hours (direct labor hours + overtime hours) could be a predictor of total aircraft produced. No regression model for measuring productivity could be developed from the data due to the limited availability of data.

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